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FINAL REPORT

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WETLANDS FOR [redacted]
TREATMENT OF ACID MINE DRA[redacted]NAGE

JOHNSON FIELDS AREA
SAND COULEE, MONTANA

JANUARY, 1987

Prepared for:

Abandoned Mine Reclamation Bureau
Montana Department of State Lands
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January 30, 1987

Mr. Mike Hiel
Dept. of State Lands
1625 Eleventh Avenue
Helena, MT 59620

Dear Mike:

Transmitted herewith are three copies of the Final Report for the Wetlands for Treatment of Acid Mine Drainage in the Johnson Fields Area near Sand Coulee, Montana.

This report presents information on the two wetlands in the Johnson Field Area through the end of 1986. This includes a literature review of passive mine drainage treatment technology; a presentation of wetland design and construction methods; and a comprehensive presentation of those data recorded through the end of 1986. The results are discussed and recommendations made.

The intent of the project considered in this report was to develop two experimental wetland ecosystems and evaluate their effectiveness at removing metal ions and modulating low pH values. The limited data available prevents a conclusive analysis of many of the factors affecting wetland performance. The time of year when the methods were constructed, inadequate time for wetland establishment, and inconsistent monitoring impacted analysis.

However, continued monitoring will allow for a more complete analysis of wetland performance to be made in the future. Experience from this project has already provided for design improvements which can be included in future wetlands projects.

This report was prepared and edited by OEA Research of Helena, Montana as a subconsultant to Robert Peccia & Associates. Input from Robert Peccia & Associates and Dr. Bill Olsen was incorporated into this report.

If you have any questions or comments regarding this report, please do not hesitate to contact Chris Hunter at OEA Research, Bill Olsen, or myself.

Sincerely,

ROBERT PECCIA & ASSOCIATES

Frank Kerins, Jr.

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INTRODUCTION

Acid mine drainage (AMD) from abandoned coal mines throughout the United States degrades the quality of waters in hundreds of drainages. In Montana these AMD discharges often contain concentrations of toxic heavy metals which pose a threat to the public health and safety. Treatment of AMD to reduce acidity and heavy metals concentrations is expensive. For most treatment methods there is a significant on-going cost due to maintenance, power and necessary supplies. During the last ten years there has been an increasing interest in treating these discharges using biological methods. These treatment schemes are relatively low cost initially and have very little operation and maintenance costs.

This report documents the efforts associated with the first attempt in Montana to treat AMD with a biological system. This study was funded by the Abandoned Mine Reclamation Bureau of the Montana Department of State Lands. Project administration was provided by Mr. Mike Hiel of the AMR Bureau. Prime contractor for the project was Robert Peccia and Associates of Helena, MT. OEA Research and Mr. Bill Olsen also of Helena provided subcontract services in the area of biological science.

The first step in this project was the completion of a literature review. The purpose of the literature review was to develop a thorough understanding of AMD, to learn as much as possible about naturally

occurring ecosystems that could be re-created to treat AMD, to determine construction techniques used in other biological treatment schemes and to evaluate their success. The information obtained during the literature review was used to design a treatment system which was constructed in July, 1986 in the Johnson Fields area near Sand Coulee Montana (Figure 1).

A program of water, soil and plant tissue sampling was conducted from the time of construction through December 1986. The resulting data were analyzed to determine the effectiveness of the wetland in removing metals and moderating the acidity of the AMD.

LITERATURE REVIEW

The formation of acid mine drainage is generally attributed to the oxidation of iron sulfides (pyrite) (Guertin et al, 1985). In this chemical reaction, which is facilitated by a bacterium, iron is released into solution and sulfuric acid is produced. At first there is usually enough natural alkalinity in the water to prevent the iron from remaining in solution, it is precipitated forming the characteristic yellow sediment known as "yellow-boy" which is often associated with AMD. However, as the reaction continues the naturally occurring alkalinity is consumed by the reaction and the pH of the water is reduced; the water becomes increasingly acidic. As the reaction continues further, other metals such as cadmium, copper, lead, zinc and manganese are released from their sulfide forms through the oxidizing action of ferric ions (Guertin et al 1985).

The treatment of AMD involves removal of metals from the discharge

and modulation of the pH. The metals can be removed from solution by increasing the pH past the solubility range of the metal in question. At

Figure 1. Location map

this point the metal ions will precipitate as insoluble compounds.

Interest in using wetland ecosystems to treat AMD appears to have been spurred by a study conducted by a group from Wright State University (Huntsman et al 1978). This group was studing a Sphagnum moss bog in Ohio to determine the adverse effects of acid mine drainage on wetland vegetation. They found that there were no adverse effects and demonstrated instead that the mine discharge was treated as it moved through the wetland. The pH of the water increased from 2.5 where it entered the wetland to 4.6 where it exited. Concentrations of iron, magnesium, sulfate, calcium and manganese all decreased as well. A natural outcrop of limestone located at the downstream end of the bog provided additional neutralization raising the pH of the effluent water to between 6 and 7.

A similar result was reported by a group studying a natural wetland area in northern West Virginia (Wieder et al 1982).

A wetland is a natural ecosystem which consists of several parts including soil, water, plants, algae, and microorganisms. Each component of the ecosystem can play a role in the treatment of AMD. Peat soils from wetlands have many characteristics which distinguish them from mineral soils. Organic soils, as compared to mineral soils, have high water holding capacity, low hydraulic conductivity, high organic matter content, and extremely high cation exchange capacity (Richardson et al, 1978). The high organic matter content and cation exchange capacities make peat soils an excellent medium for removing metal ions from solution. Rashid, as reported in Forstner and Wittman (1981) stated that one third of the

total bonding capacity in humic matter may be attributed to cation exchange while the remaining two-thirds are attributed to chemical sorption and organic acid complexes.

Wetland vegetation is also capable of removing metal ions from solution. This can be done in any of several ways. As with peat, metal ions can be adsorbed to the surface of the plant tissue chemically or through cation exchange at the cell tissue surface. In addition the plant can take the metal ions into the roots and transport it to the leaves or flowers as required. The species of plant and metal ion involved are important variables. Hutchinson (1975) for example reports that within the family Nymphaeaceae, Nuphar markedly concentrates strontium while Nymphaea excludes it. Table 1 (from Hutchinson, 1975) reports the concentration of aluminum in various plant parts for two species of water lily (Nuphar advena and Nymphaea odorata).

Table 1. Aluminum (ppm) concentration in water lilies

Study	leaf petiole	leaf	flower stalk	flower
Nuphar advena				
Cedar Lake	230	510	260	270
Linsley Pond	300	390	330	340
Nymphaea odorata				
Cedar Lake	420	730	180	1250
Linsley Pond				

(1971)	180	610	370	1730
(1972)	199	179	188	194

This table points out that these plants are concentrating aluminum from the water column, that there are differences in uptake between species, and that species and metal ion involved are not the only two important variables involved in plant uptake of metals.

Table 2 provides data from Seidel (1976) reporting the absorption of selected ions by various macrophytes. Uptake figures are given in mg/kg dry weight and mg/m^2 of growth area.

Table 2. Absorption of chemicals by various macrophytes

	Cu		Co		Zn		Ni		Mo		Mn		B	
	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2
Scirpus lacustns	4.8	16.13	5.63	2.28	50	168.00	1.71	5.75	0.55	1.85	1200	4032.00	14.6	49.6
Carex sincta	5.6	15.23	8.72	1.96	63	171.36	2.46	6.69	0.29	0.79	970	2638.4	21.4	58.21
Ins psaudacorus	5.7	14.14	1.11	2.75	50	124.0	1.75	4.34	0.33	0.93	382	947.36	10.3	25.41
Typha angustifolia	4.7	6.77	0.44	0.63	43	62.92	1.86	2.68	0.30	0.43	779	1121.76	24.5	35.28
Glycana aqúalica	5.6	11.65	0.48	0.99	73	151.84	1.99	4.14	0.24	0.49	586	1218.88	15.0	31.20
Phragmitas communis	4.2	18.82	0.62	2.78	37	165.76	1.53	6.85	0.26	1.18	166	743.68	8.2	36.74
Acorus calamus	4.1	6.56	0.53	0.85	38	60.8	1.08	1.73	0.30	8.48	383	612.8	56.9	91.04
Sparganium eroctum	5.6	7.17	1.07	1.37	76	97.28	2.27	2.91	0.24	0.31	604	773.12	40.2	51.46
Myosotis palusuis	12.2	3.90	1.44	0.46	104	33.28	3.19	1.02	0.53	0.17	2000	640.0	30.8	9.86
Mantha aquatica	8.5	14.28	0.54	0.91	78	131.04	2.03	3.41	0.47	0.79	381	640.1	38.3	64.34

	Ca		Mg		P		K		Na		Fe		Si	
	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2
Scirpus lacustris	3.95	12.17	0.98	3.29	2.00	6.72	10.30	34.61	6.30	21.17	0.78	2.62	12.60	43.34
Garex sincta	4.84	13.16	2.06	5.60	2.20	5.93	13.90	38.31	2.20	5.58	3.80	10.34	17.60	47.87
Iris pseudacorus	16.97	42.09	2.58	6.39	2.50	6.20	35.40	87.79	1.70	4.22	1.30	3.22	4.30	10.46
Typha angustifolia	14.36	22.48	1.49	2.29	2.20	3.17	14.10	20.30	12.20	17.57	1.10	1.58	3.70	5.33
Glycana aquatica	4.79	9.96	1.46	3.04	2.50	5.20	26.00	54.00	1.20	2.50	1.30	2.70	14.80	30.78
Phragmites communis	1.70	7.62	0.82	3.90	1.40	6.27	8.10	36.29	1.10	4.93	0.92	4.12	21.70	97.22
Aconis calamus	12.33	19.73	1.84	2.94	2.90	4.64	20.00	32.00	4.10	6.58	0.97	1.55	3.30	5.28
Sparganium cractum	10.11	12.94	2.10	2.69	3.90	4.99	24.80	31.74	6.80	8.70	3.60	4.61	6.80	8.70
Myosotis palustis	9.13	2.92	1.50	0.48	2.00	0.64	42.50	13.60	5.00	1.60	10.20	3.26	8.30	2.66
Menthe aquatica	16.95	28.48	1.58	2.75	2.20	3.70	10.50	17.64	6.90	11.59	3.10	5.21	4.10	6.89

Hunter (1986) conducted an extensive review of the literature pertaining to concentration of trace metals by algae. Table 3 summarizes

the results of this review. The term concentration factor as used in this table is defined as: $CF = {}^{c}/_{c^1}$

Where c = the concentration of the trace metal in the aquatic organism and c^1 = the aqueous medium metals concentration. Concentration factors were found to range from 10^2 to 10^4 for a variety of algae species and metal ions.

Trollope and Evans (1976) conducted studies of metal accumulation by algae in British streams polluted by mining and smelting wastes. They selected waters adjacent, near and distant (actual distances not provided by the authors) from zinc smelting wastes and collected water and algal samples from these waters. The authors noted that algal blooms appear to regulate uptake of individual metals. For the three groups, mean metal concentrations in the algae were ordered as follows:

Fe > Zn > Pb > Cu > Ni,

while the mean metal concentrations in the water bodies were

distant: Fe > Zn > Ni, Pb > Cu

near: Zn > Ni > Pb > Fe > Cu

adjacent: Zn > Pb > Fe > Ni > Cu.

In 1967 a large study was undertaken of industrial treatment of heavy metals to protect aquatic systems (Jennet and Wixson 1975). The new lead belt of southeastern Missouri was developing quickly. High concentrations of lead, zinc, copper, and manganese were found in the streams, and aquatic insect diversity was declining. This information caused several mining/milling companies to change their waste water treatment programs. Previous work by Wixson and Jennett had shown that algae

effectively removed heavy metals. Because of the capacity of algae to concentrate heavy metals, a series of shallow and meandering channels was constructed and populated by a mixed algae community. The smelter effluent was passed through the meander channel prior to discharge to the receiving stream. Algae trapped the metals, and when the algae broke loose they were trapped in a final sedimentation basin. Based on total heavy metals removed, the system was 99%+ effective.

Darnall (in press) has shown that cultured Chlorella vulgaris may have economic potential for recovery of metal ions. The cultured algae are harvested by centrifugation, dialyzed against de-ionized water, and lyophilized for storage. The algae are then immobilized in polyacrylamide and packed in a column. Several metal ions are bound by Chlorella between pH 5 and 7: chromium, cobalt, nickel, copper, zinc, silver, gold, mercury, cadmium, lead, uranium, iron, beryllium, and aluminum.

Little work has been published regarding the uptake of trace metals by microorganisms. However many of the authors reviewed hypothesized that microorganisms were facilitating uptake by soils, plants and algae.

We conclude on the basis of the literature review that several of the individual components of a wetland; soils, vegetation and algae, are capable of concentrating trace metals from the water column.

Several publications were reviewed to learn as much as possible about wetlands construction techniques. The principal source of information on this topic was a set of course notes prepared by Kleinmann et al (no date) for a class called Constructing Wetlands for the Treatment of Mine Water. In the preface to this publication the authors warn that constructing

wetlands to treat acid mine water is experimental technology and that practitioners should expect to make mistakes. Key points emphasized in this publication include:

-sizing the wetland and limestone channel to allow treatment of the expected quantity of water during all seasons and expected precipitation events. As a rule of thumb 200 square feet of wetland for each gallon of maxiumum flow is recommended.

-A minimum of 12 inches of organic substrate is recommended.

-The difference in the pH of water and soil between the source of the wetland vegetation and the wetland being planted should not exceed 2 pH units.

-Water velocities of 0.1 - 0.3 feet/second are good starting velocities for iron and manganese removal.

-Side slopes of the wetland < 15% are recommended for aquatic vegetation. Water depths should vary between 2 inches and 1-2 feet throughout the wetland.

-Planting of rhizomes, tubers and rootstocks should occur in early spring.

-Optimum wetland soils for emergent hydrophytes (such as cattails) are composed of finely decomposed organic matter with some mineral soil component.

-By providing a diversity of slopes, depths, and substrates, planted and pioneering vegetation should develop a well-mixed pattern of species.

-Care should be taken to avoid "short-circuiting" of the wetland via the formation of flow channels through the wetland.

The literature review also revealed that several authors had utilized

limestone channels to moderate pH after the water had passed through the wetland and metals particularly iron, had been removed (Holm and Jones, 1985; Kleinmann et al 1983). If iron is present in the water as it passes through the limestone channel, it will be precipitated on the limestone as the pH is increased. This will lead to decreased effeciency in the pH moderation phase.

WETLAND DESIGN AND CONSTRUCTION

The sites where the wetlands were constructed are located on the Johnson Ranch next to a field just north of the town of Tracy, Cascade County, Montana. The sites were chosen for a number of reasons, including:

- There were two different controlled flows of less than 15 gpm in proximity to each other;
- The two flows had different pH's and metal concentrations;
- The sites were easily accessible; and
- The geometry of the sites provided for some freedom in the design of the wetlands.

These two sites were designated as being located at the South Adit (large wetland) and the East Adit (small wetland).

The South Adit produces a flow of about 15 gpm. This flow is collected at the mouth of the adit by an underground collector, flows into a four-inch PVC line and into a manhole which drains into a four-inch PVC line extending to Sand Coulee Creek. The length and fall of the PVC line between the collector and the manhole allowed for the design of the large wetland to provide for tapping into the flow below the collector, passing

it through the treatment system, and directing it into the four-inch PVC just above the manhole.

The East Adit produces a flow of about six gpm. This flow is collected at the mouth of the adit by an underground collector and flows into a four-inch PVC line which extends to the same manhole into which the flow from the South Adit drains. The geometry of the pipe locations at the East Adit did not provide for the effluent from the treatment system to be directed back into the PVC drain system.

The PVC drain system was installed as an AMR Bureau project in 1982.

The primary criteria used for the design of the wetlands were the provisions for a minimum of 200 square feet surface area per gallon per minute of flow, a minimal drop from inlet to outlet, a maximum one percent channel gradient through the wetlands, and channel sinuosity to maximize the water-peat contact.

The large wetland was designed as a rectangular impoundment with the approximate dimensions of 100 feet by 45 feet (Figure 2). This impoundment was baffled by a berm extending 90 feet along the length of the wetland from each side of the wetland. This baffling provided sinuosity for the flow through the wetlands and prevented short-circuiting of the flow across the wetlands.

The large wetland (Figure 3) is located on a north-facing hillside. The length of the wetland runs approximately east-west. The flow enters the wetland from the four-inch PVC line through an inlet structure with a triangular notch weir at the southeast corner of the wetland. The flow exits at the northwest corner of the wetland through an oulet structure

with a rectanglular weir. This weir establishes the water level in the wetland. The flow from the outlet structure passes over three reaeration structures and approximately 120 linear feet of limestone channel before entering the four-inch PVC line to the manhole. Each of the reaeration strucutures has about 1.5 feet of fall.

The small wetland was designed as two parallel linear impoundments connected at one end by a reaeration structure forming essentially a U-shaped wetland. Each of the impoundments are about sixty feet long and

Figure 2. Large wetland, aerial and side views.

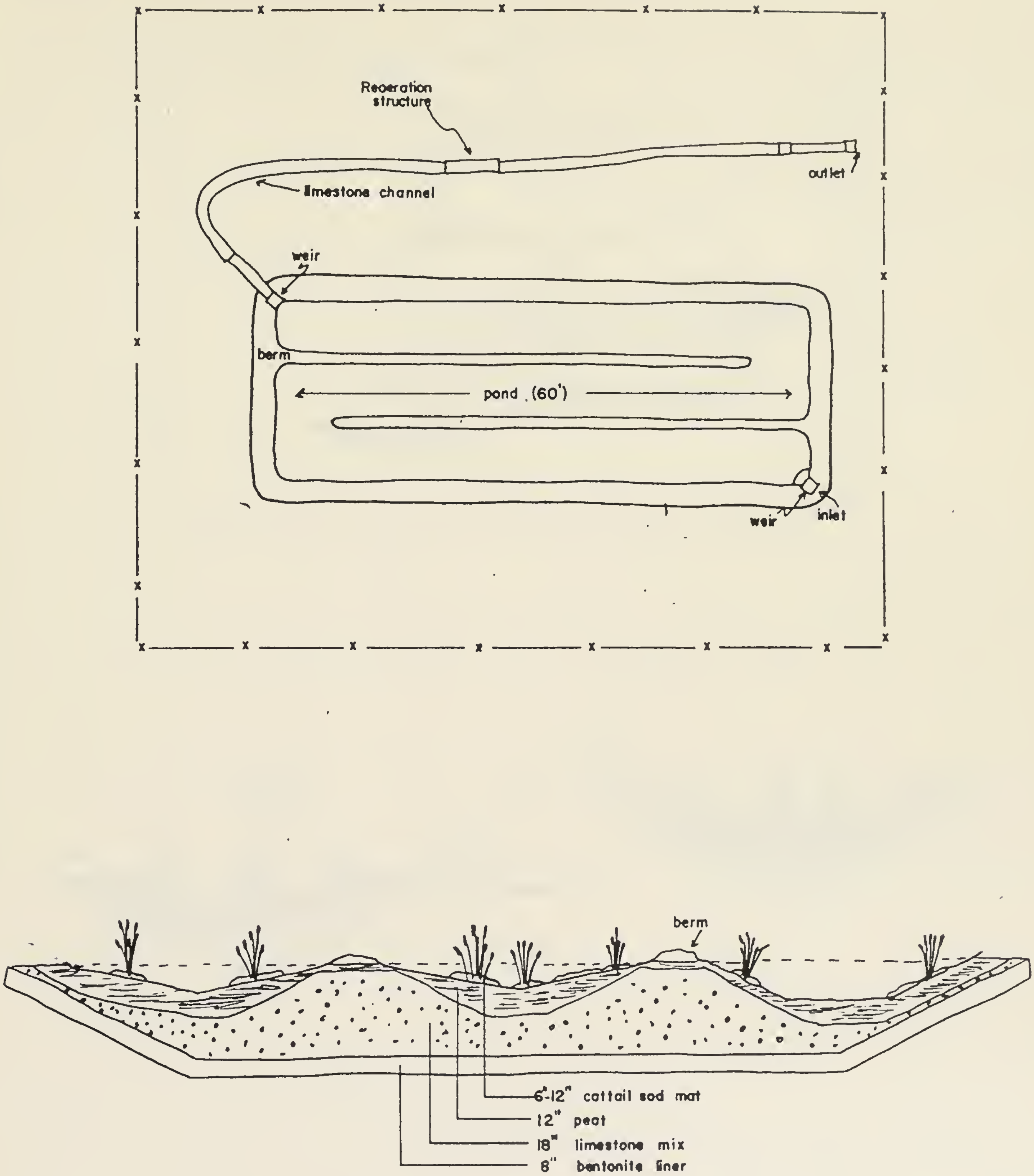
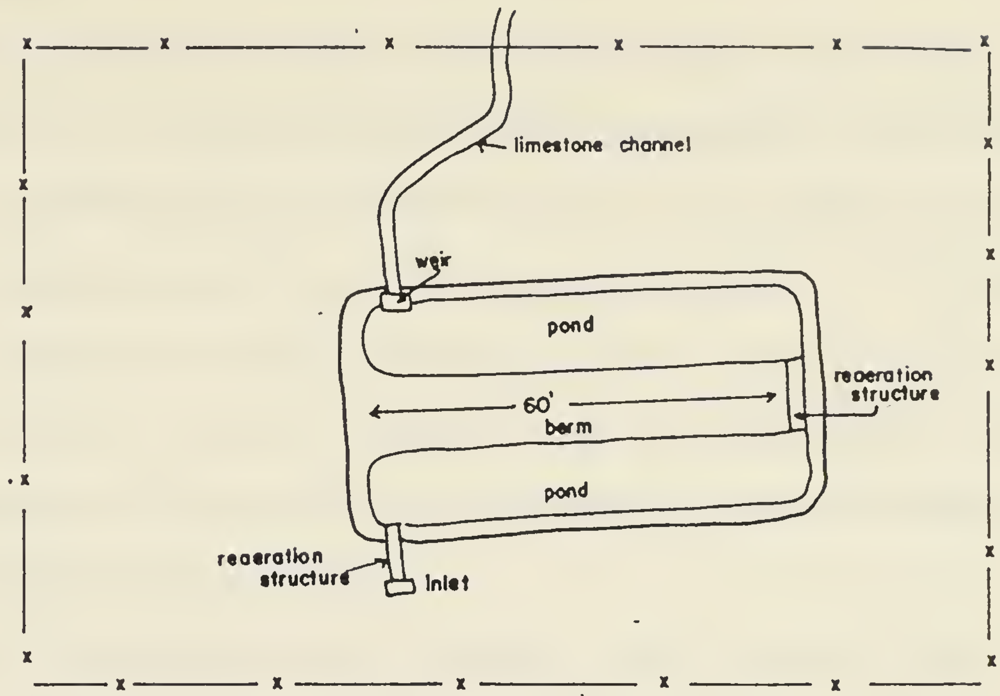
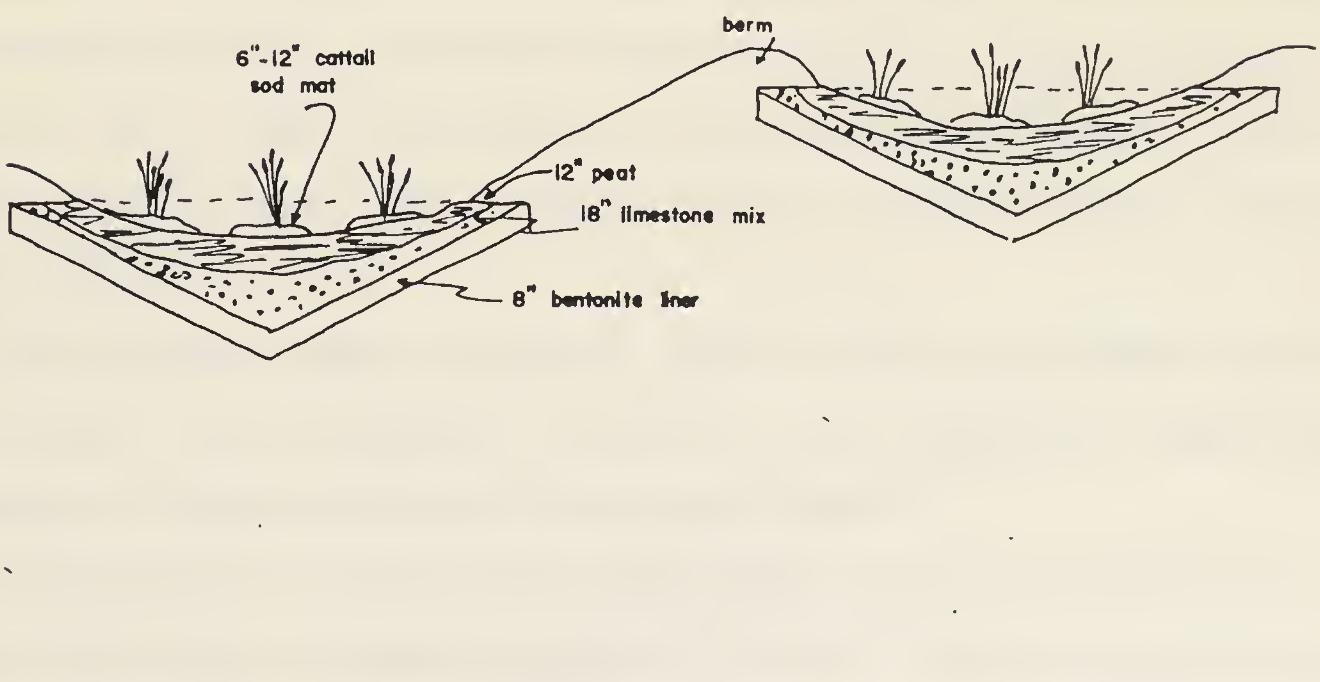


Figure 3. Small wetland, aerial and side views.





ten feet wide. The reaeration structure connects the eastern edge of the impoundments.

The little wetland is located about 200 yards east of the large wetland. The length of the impoundments runs approximately east-west. The flow enters the wetland from the four-inch PVC line through an inlet structure with a rectangular weir at the southwest corner. The flow exits the wetlands through an outlet structure at the northwest corner. The flow from the outlet structure passes over two reaeration structures and approximately thirty-seven feet of limestone channel before draining into a wet area below the wetland.

The soil underlying both wetlands was amended with bentonite to prevent infiltration of the water in the impoundments into the ground. The base of both wetlands and the berms used for baffling in the large wetland were made of a soil limestone mix with a minimum depth of 18 inches. A minimum of 12 inches of peat was placed over the base material. Four-foot by nine-foot cattail sod mats were placed on top of the peat and spaced evenly over approximately 40% of the area of the wetlands. One-foot by one-foot mats of sedge sod were placed randomly throughout the wetlands.

The interested reader wishing to obtain addition information regarding the design of the wetlands is referred to the preliminary design report prepared by Robert Peccia and Associates (1986).

The construction phase of the project began on June 24, 1986; the work was substantially completed by July 18, 1986. The work was performed by Shumaker Trucking and Excavating under a contract with Robert Peccia

and Associates. Robert Peccia and Associates provided quality control inspection services for all of the work executed.

Appendix A contains a list of the bid items covered under the contract schedule, lists approximate quantities, and shows pertinent information for the Contractors submitting proposals for the work. Because of the uncertainty in the quantities required for completion of the project, most work items were bid out on a unit price basis. The bid price on this project was $35,544.36; the final project cost was $44,185.09.

Appendix A also contains a breakdown of the quantities of each work item for each of the wetlands constructed. A breakdown of the costs incurred for consulting and construction prior to January 1, 1987 is also provided. The additional $5,600.00 for Shumaker Trucking and Excavating over the construction costs was for an additional 200 cubic yards of peat which is stored at the Shumaker yard and on site.

MONITORING METHODS

Water Quality

The initial study plan called for bi-weekly influent and effluent water quality samples to be collected. For the first two months these samples were analyzed for a wide range of constituents including:

Potassium	Total Dissolved Solids	Total Hardness
Carbonate	Total Alkalinity	Acidity
Bicarbonate	Specific Conductance	pH

Nitrate + Nitrite	Arsenic	Barium
Iron	Sodium	Calcium
Magnesium	Sulfate	Chloride
Cadmium	Copper	Lead
Manganese	Mercury	Selenium
Zinc		

Following the initial two months, at a minimum each sample was to be analyzed for pH, specific conductivity, sulfate, total and dissolved iron and total and dissolved manganese. In addition those constituents which had been determined to be of interest based upon the initial two months of data would also be included in the analyses.

On September 30, 1986 a review of the preliminary data was conducted and it was determined that the subsequent water samples would be analyzed for the following constituents:

Metals (Total and Dissolved)

Iron	Sulfate
Aluminum	pH
Manganese	Total acidity
Zinc	Specific conductance
Copper	Temperature
	Hardness
	Redox potential

Water samples to be analyzed for dissolved constituents need to be filtered in the field prior to preservation with nitric acid. The necessary

equipment for field filtering of water samples was not obtained until the November 19, 1986 sampling episode. Prior to this date all analyses were for total metal concentrations of each ion.

Measurement of instantaneous influent and effluent flow was made at each wetland at the time the water sample was collected. The measurement was made at the inlet and outlet weirs.

Soil and Vegetation Sampling

Soil and vegetation samples were collected monthly from both ponds. Soil samples were taken from both the inlet and outlet areas of each pond. In addition control soil samples were taken from peat that had not been placed in the wetland. Control vegetation samples were collected from cattails growing in the source area.

Soil samples were analyzed for pH, conductivity, particle size, total aluminum, iron, manganese, sulfur and organic carbon.

Vegetation samples were subjected to analyses for total aluminum, iron, manganese, and sulfur.

Algae

Periodic grab samples of algae were made. Algae were identified to genus and species where possible.

RESULTS

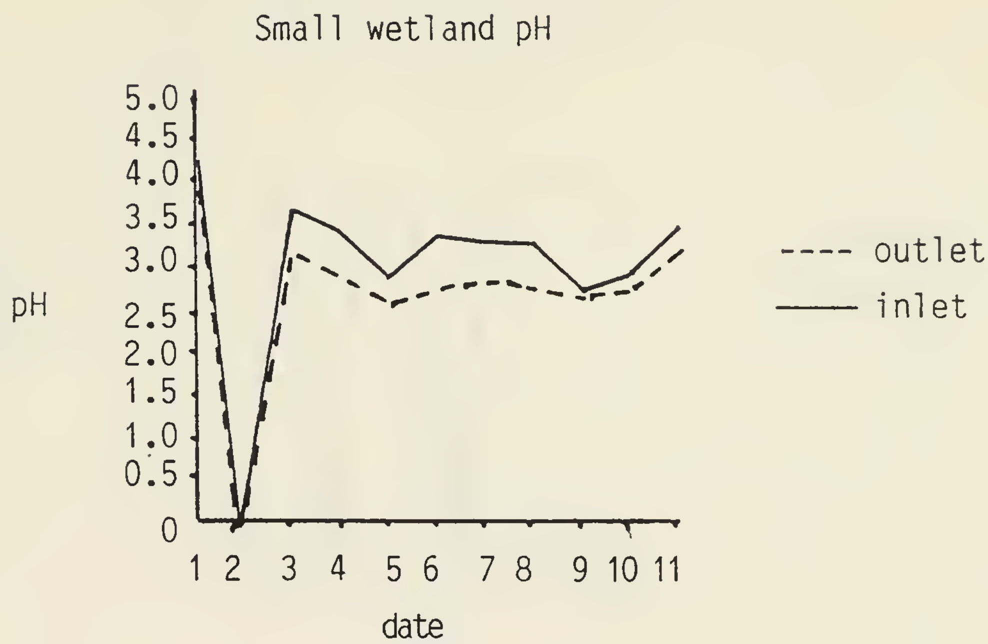
Water Quality Samples

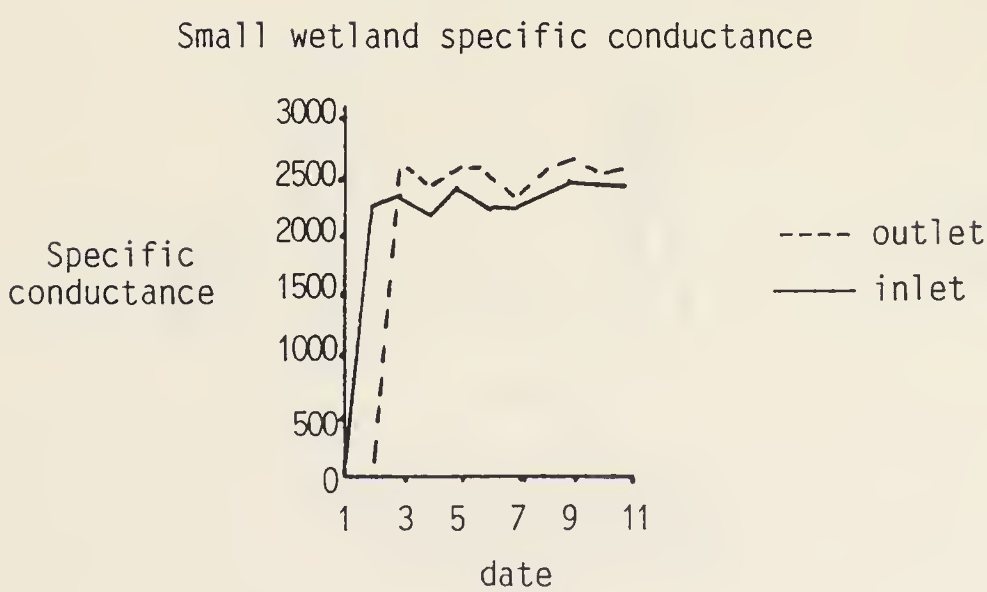
Graphs 1-6 present the water quality data for the large wetland (South) and Graphs 7-12 depict the data for the small wetland (East). These data show that influent water at the large wetland was of significantly lower quality than that entering the small wetland. It is also apparent from

Key to water sampling dates

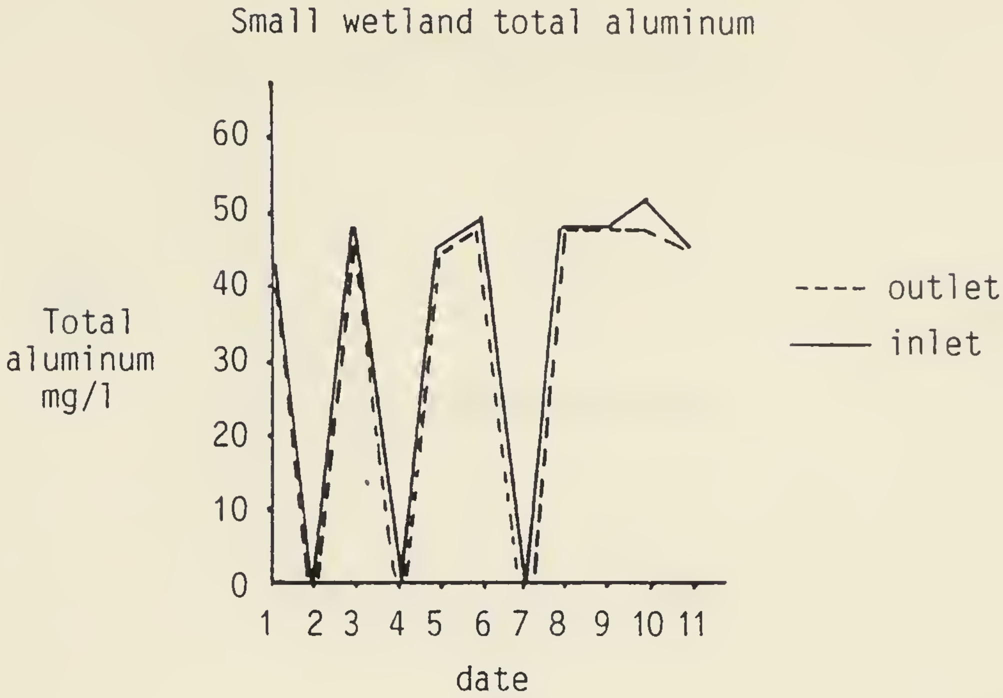
1	July 10, 1986	6	September 3, 1986
2	July 21, 1986	7	September 17, 1986
3	August 4, 1986	8	October 1, 1986
4	August 25, 1986	9	October 24, 1986
5	August 27, 1986	10	November 19, 1986
		11	December 23, 1986

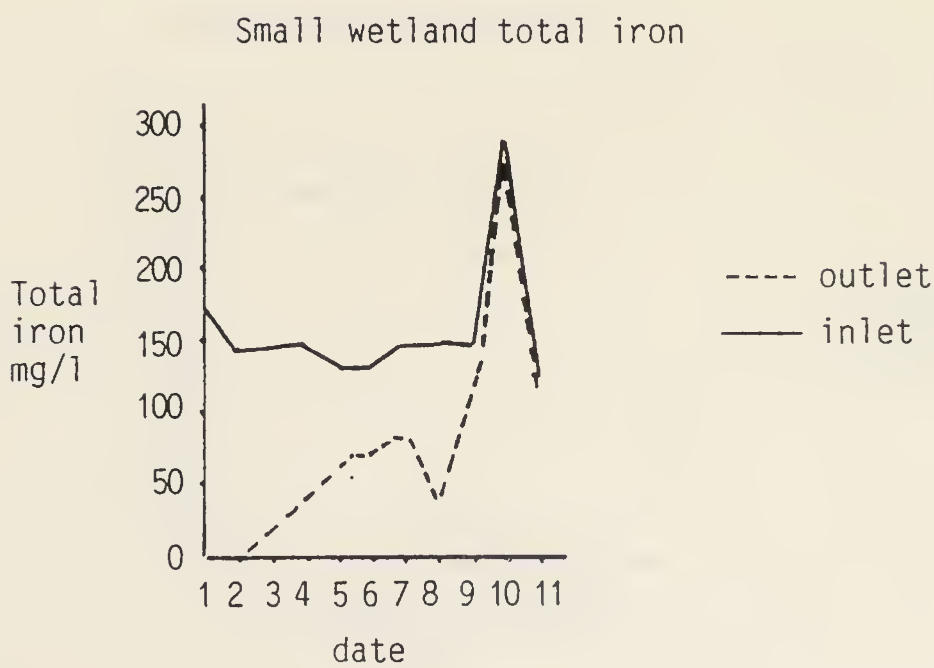
Graphs 1 and 2, small wetland pH and specific conductance.



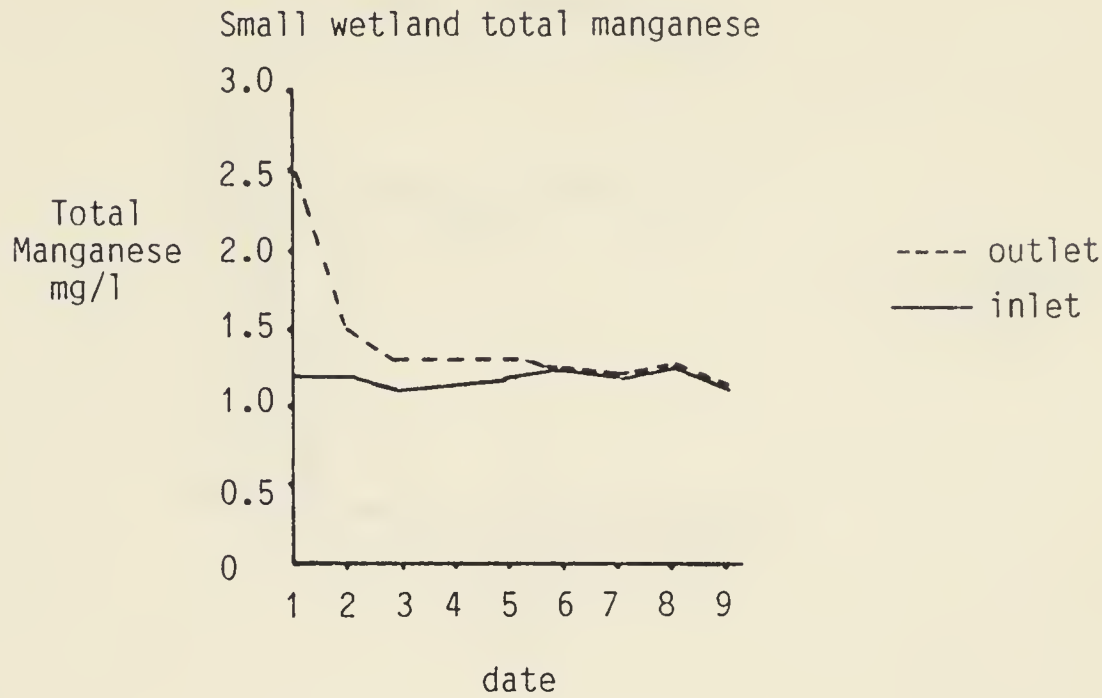


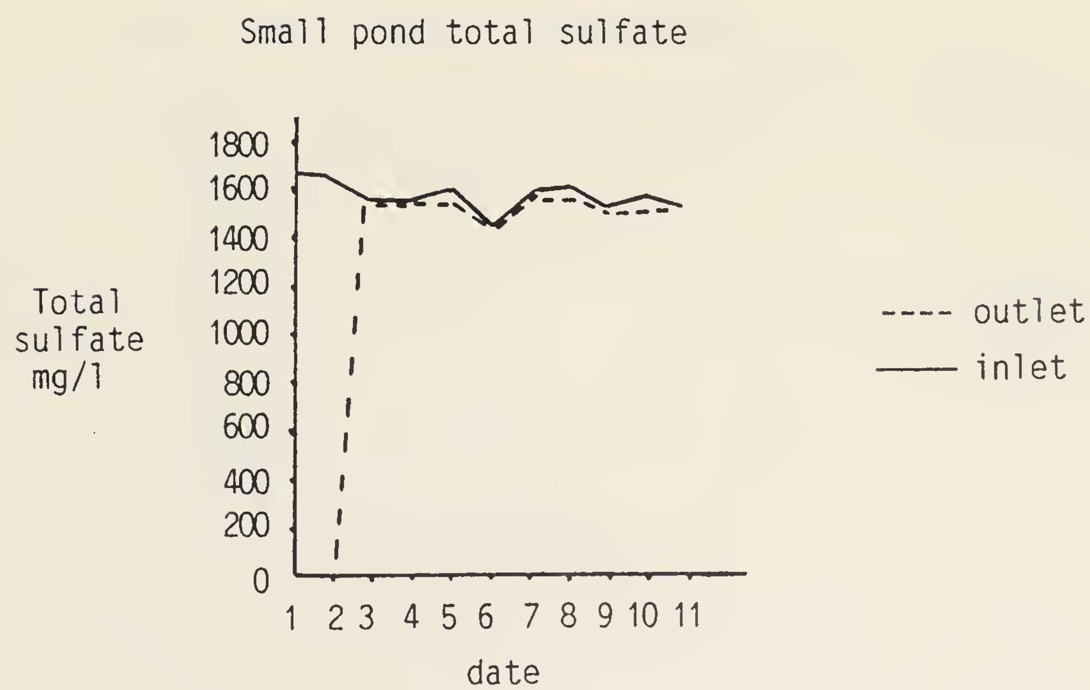
Graphs 3 and 4, small wetland total aluminum and total iron.



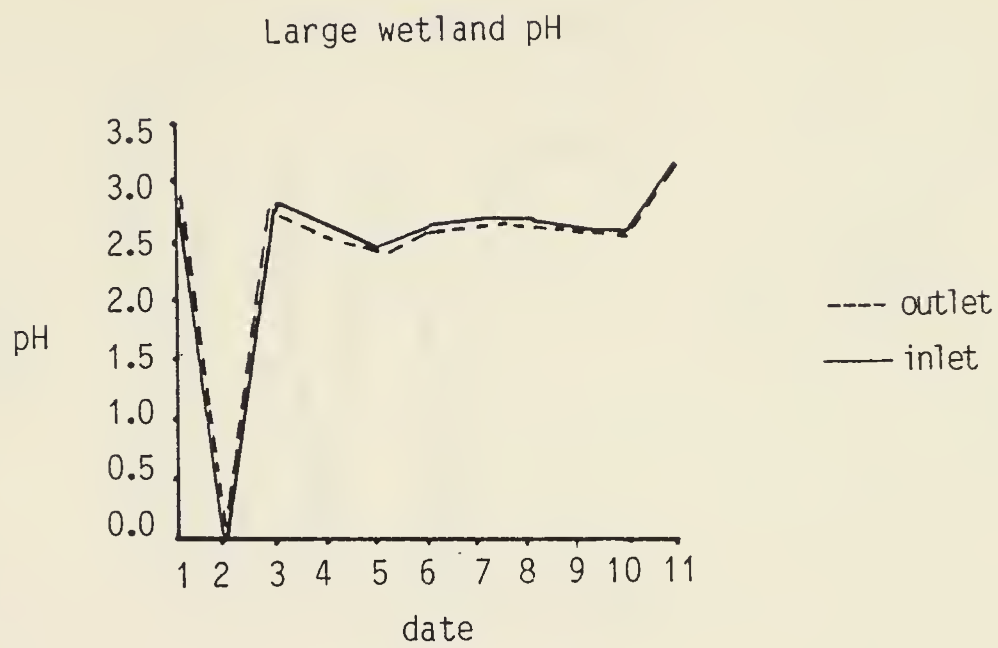


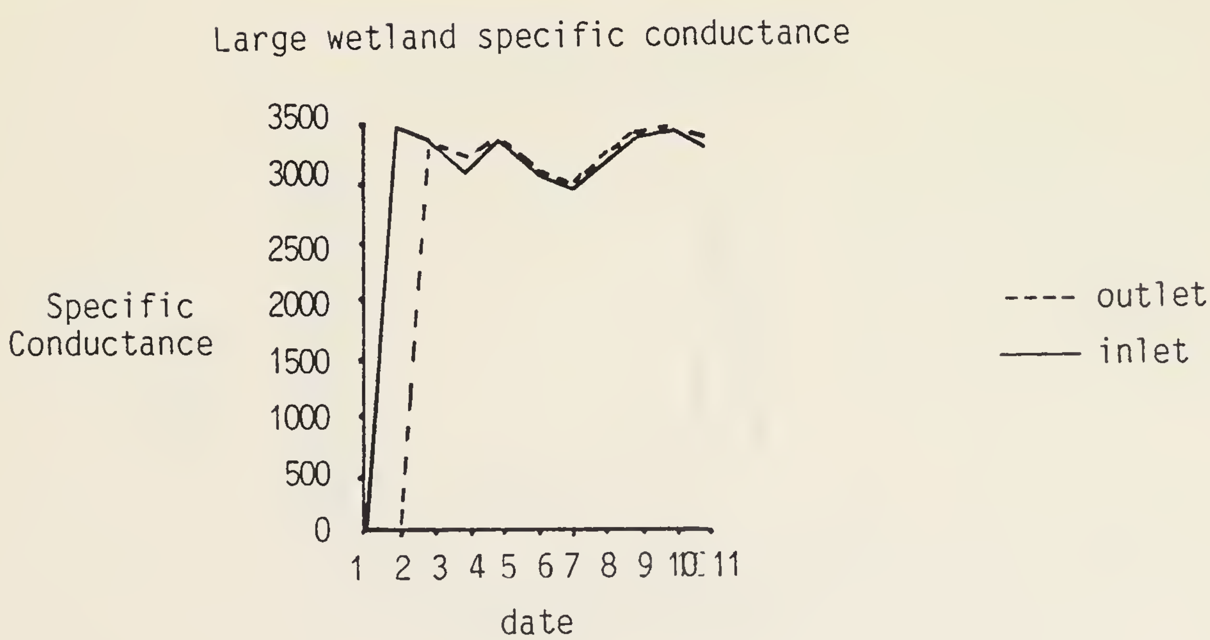
Graphs 5 and 6, small wetland total manganese and total sulfate.



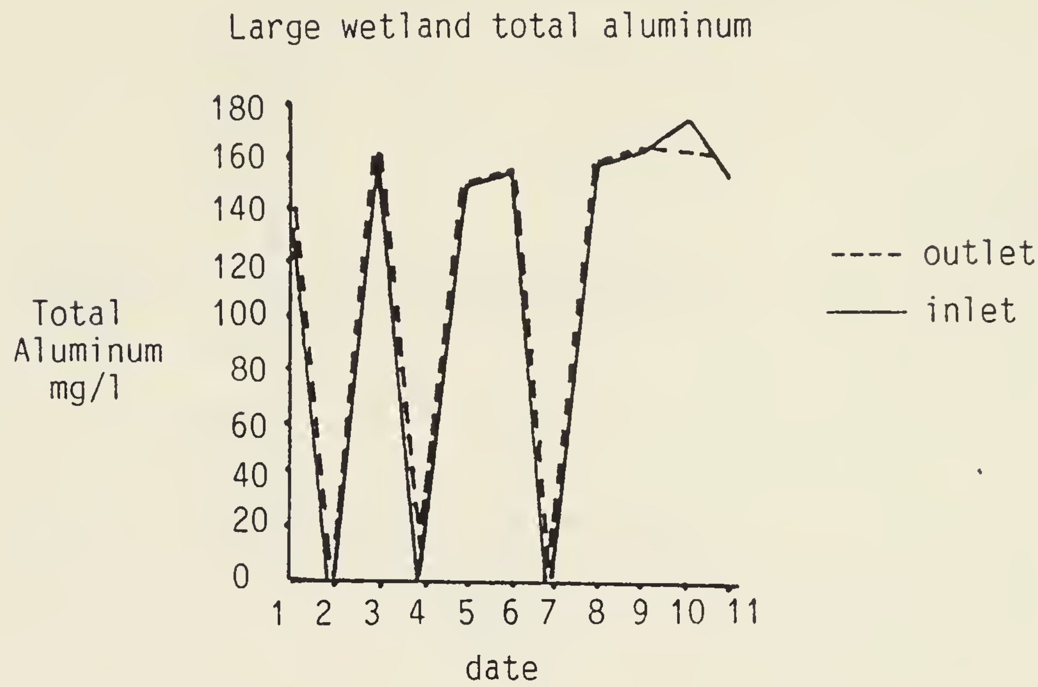


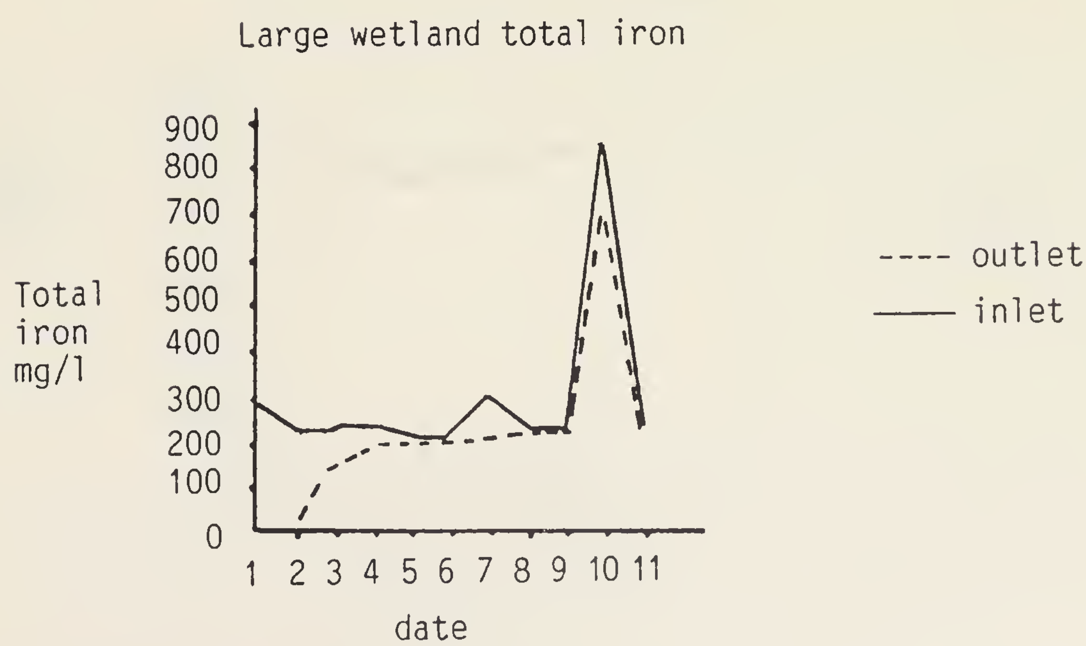
Graphs 7 and 8, large wetland pH and specific conductance.



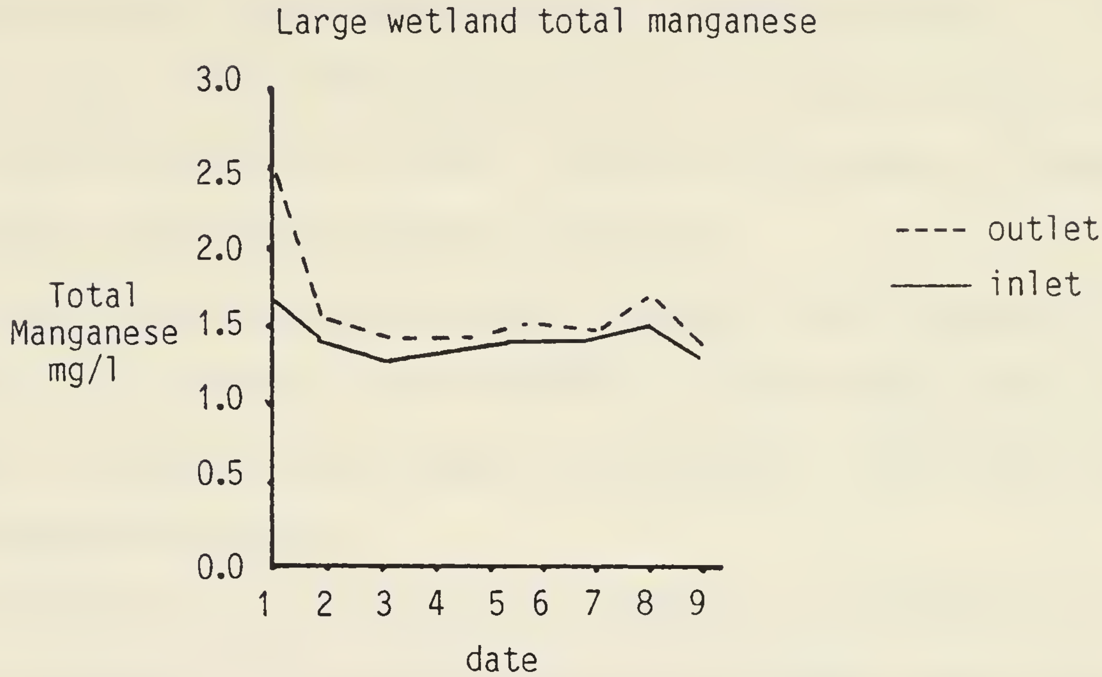


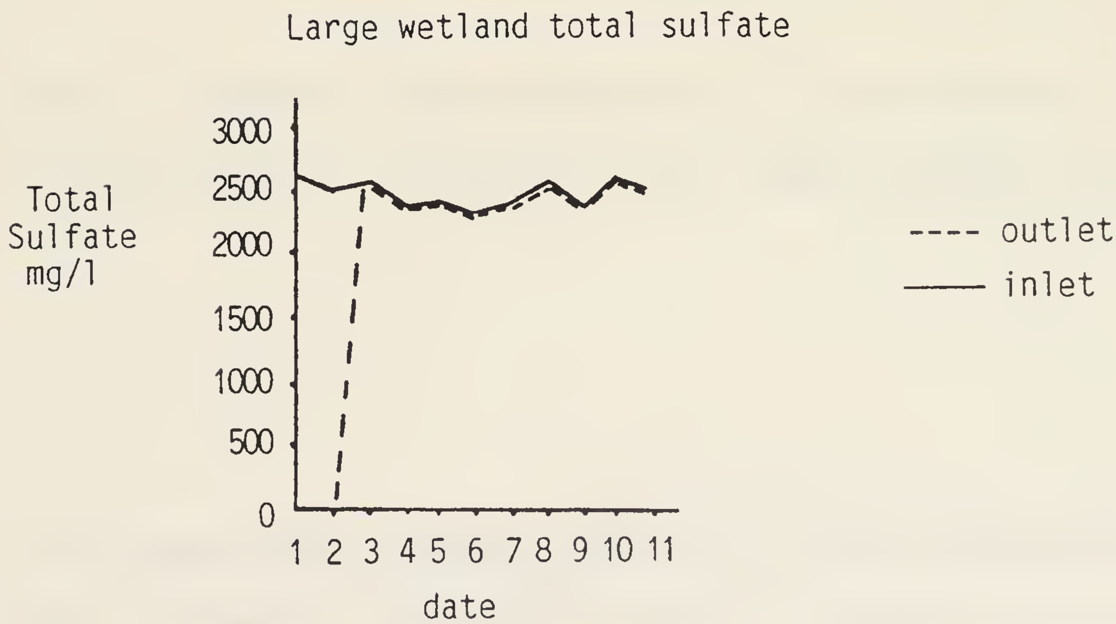
Graphs 9 and 10, large wetland total aluminum and total iron.





Graphs 11 and 12, large wetland total manganese and total sulfate.





these data that, with the exception of the first two sampling episodes following construction, there was little if any change in the measured paramenters as the water flowed through the large wetland . It appears from the August 5 and 25 samples that iron was attenuated as water flowed through the bog at this time. However there was no moderation of pH or change in the other measured parameters.

The results from the small wetland indicate that through the October 24 samples, the wetland was removing iron and that there was some moderation in both pH and specific conductance. The other parameters sampled showed no change.

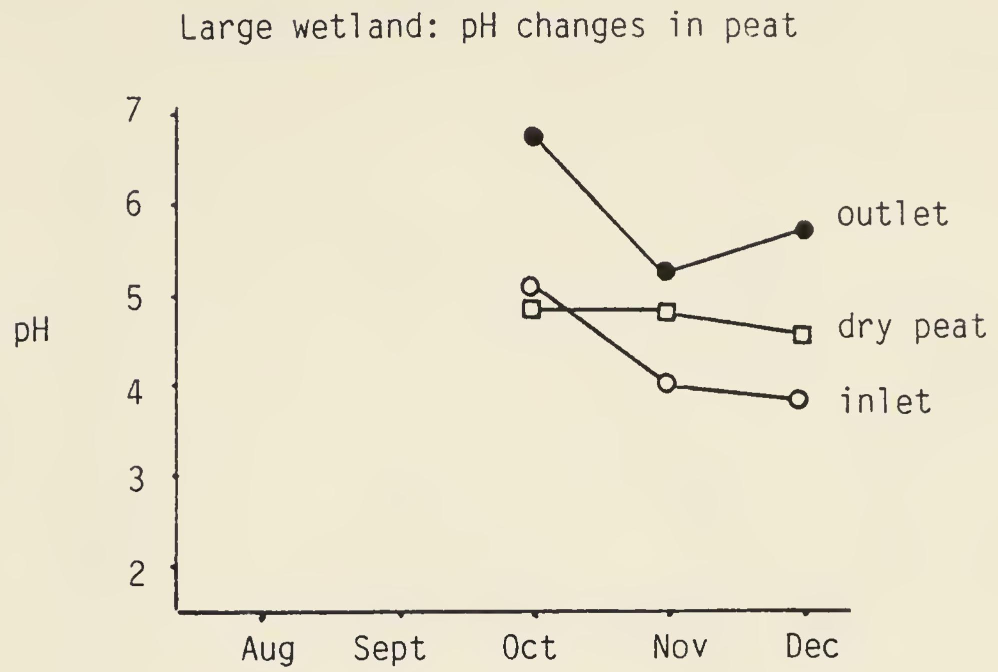
On September 3 a dye test was conducted to determine the flow rate through the wetlands. The results of that test indicated that 6 hours and 1 hour were required for water to flow halfway through wetlands 1 and 2 respectively. This was much faster that the design retention time of 36 hours and it was decided to throttle back the flow by approximately one-half.

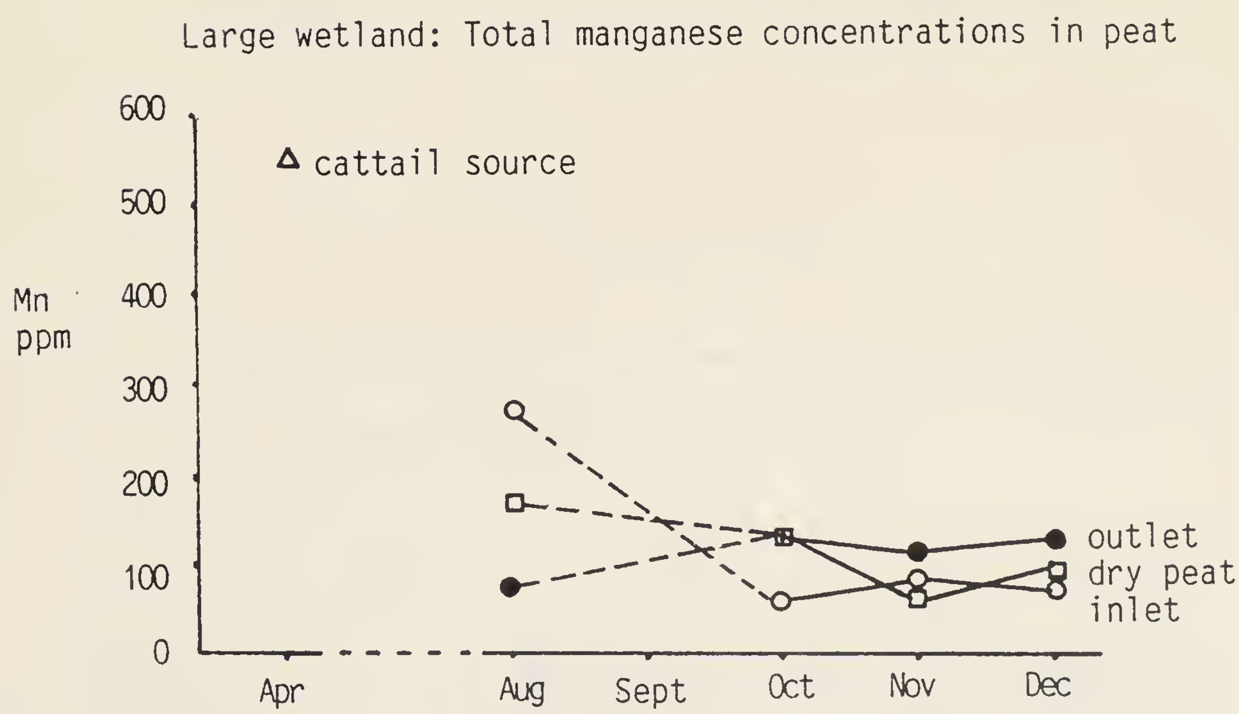
There was no change in the effectiveness of the wetlands in removing metals or moderating pH reflected in the data following this throttling back.

Soils

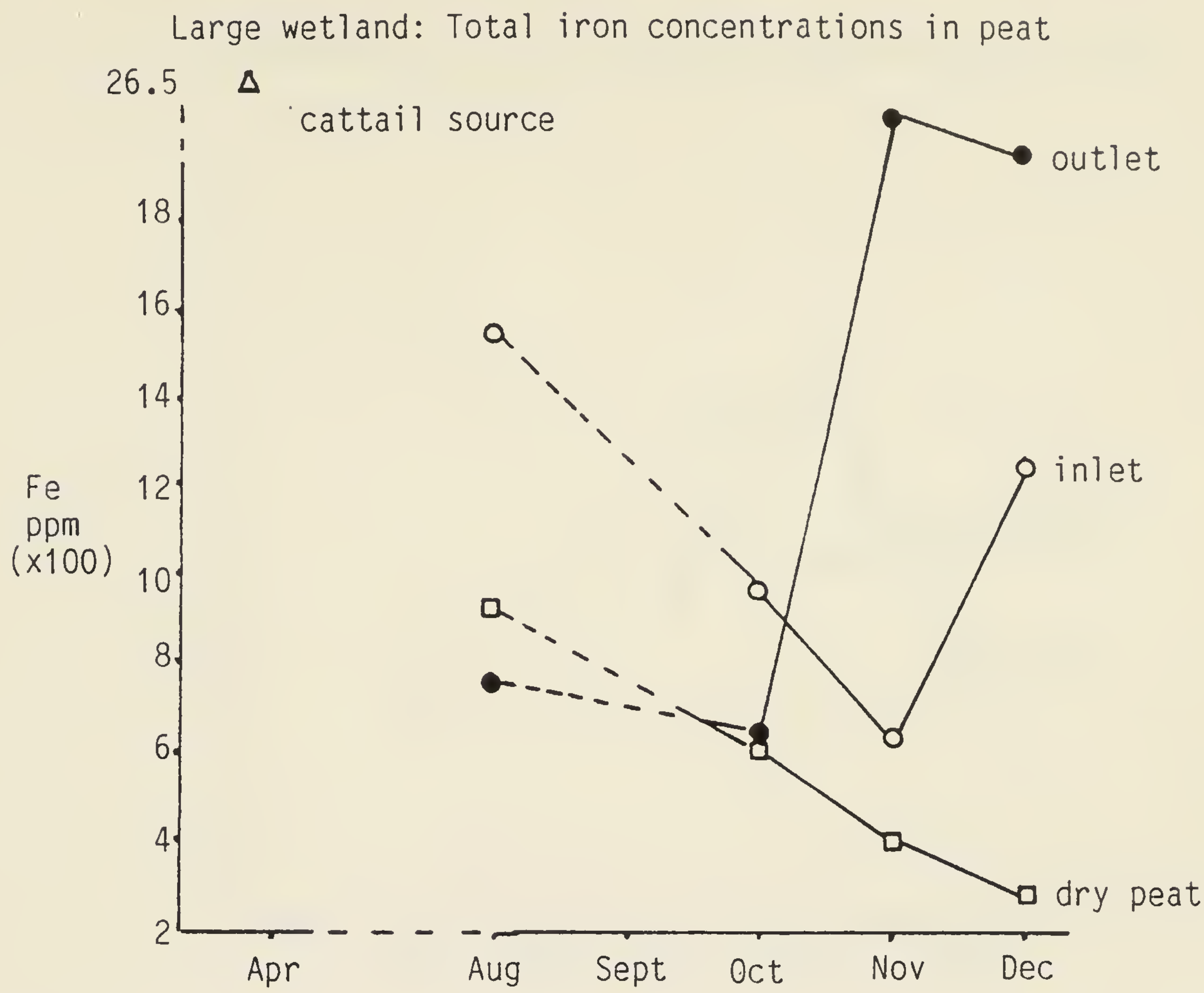
Graphs 13-19 present peat sampling data for the large wetland and graphs 20-26 present the data for the small wetland. Sampling results from the cattail source wetland and dry peat piles are given for comparison.

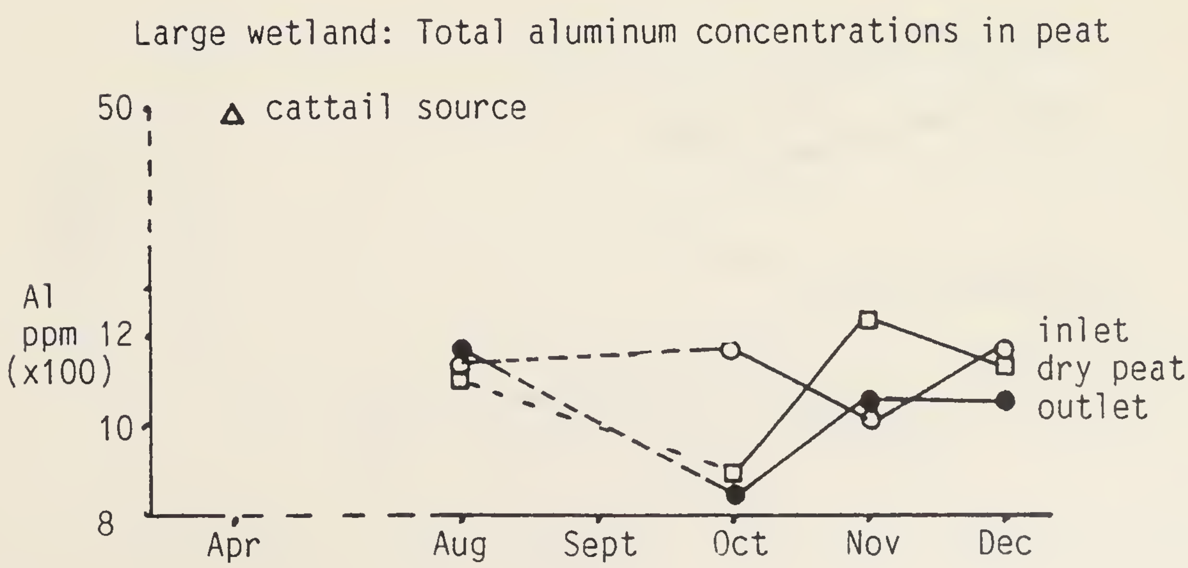
Graphs 13 and 14, large wetland pH and total manganese in peat.





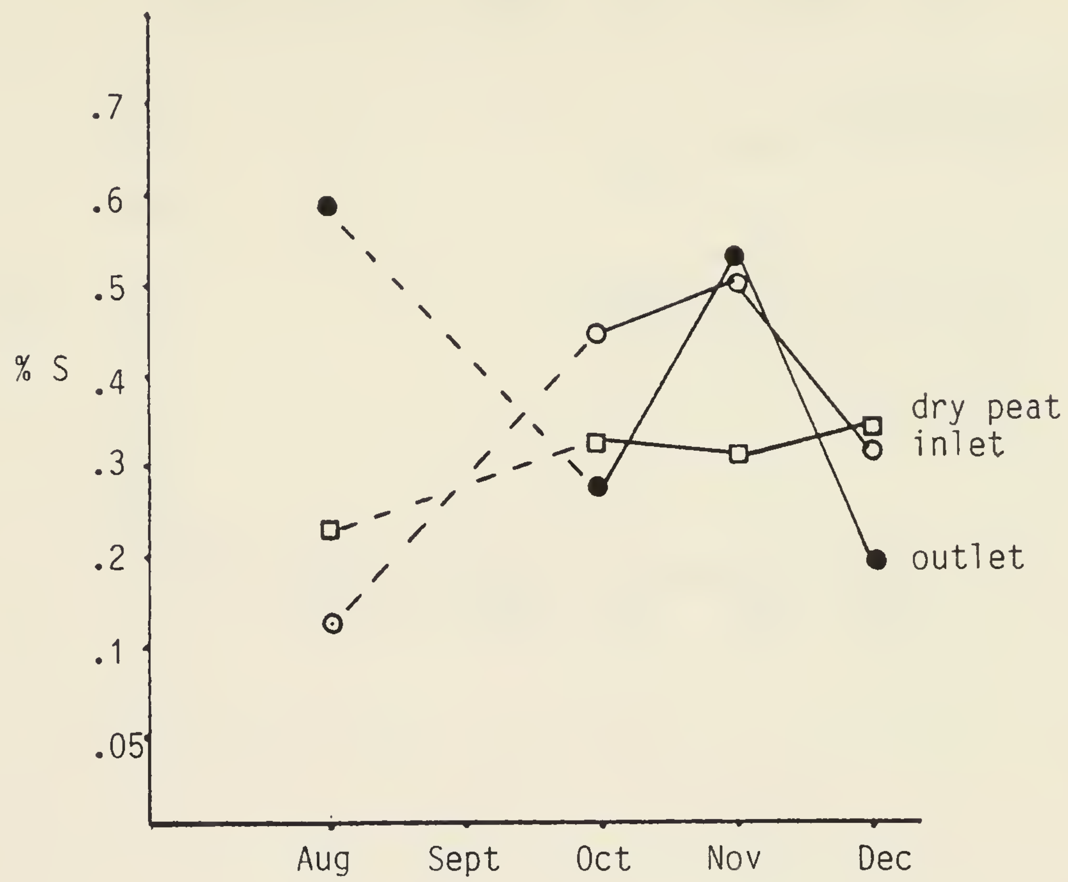
Graphs 15 and 16, large wetland total iron and aluminum in peat.



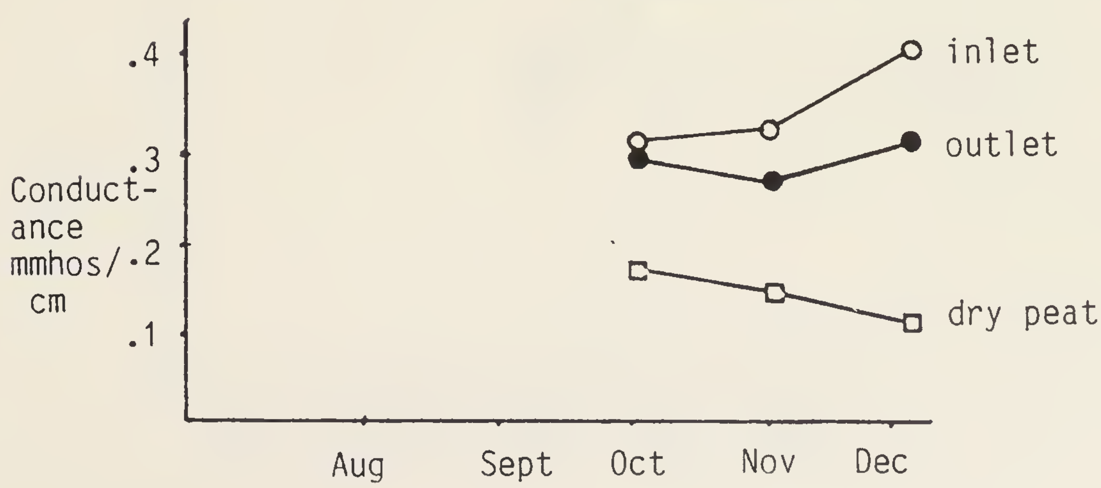


Graphs 17 and 18, large wetland total sulfur and specific conductance in peat.

Large wetland: Total sulfur concentrations in peat

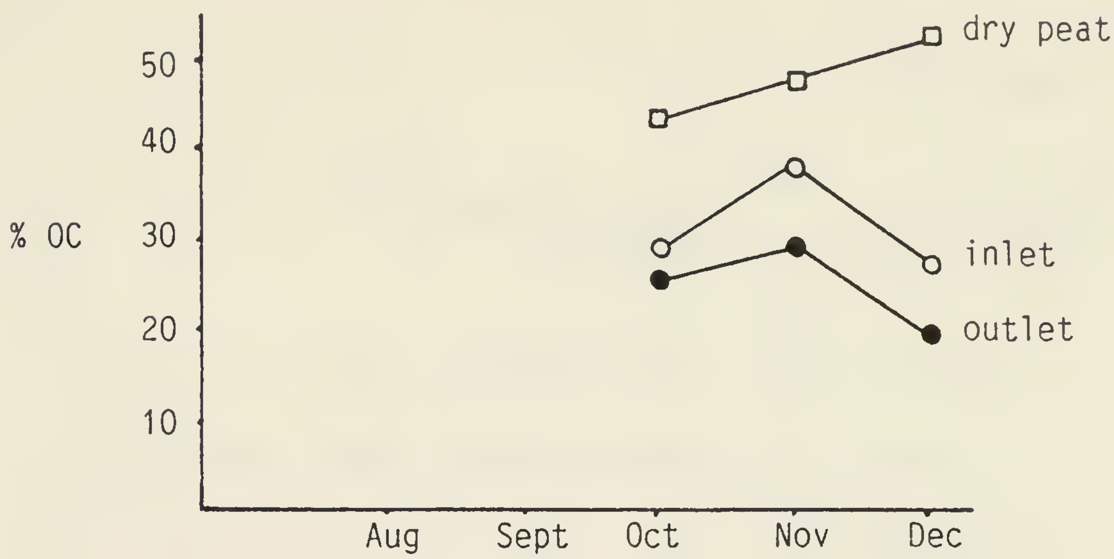


Large wetland: Specific conductance in peat

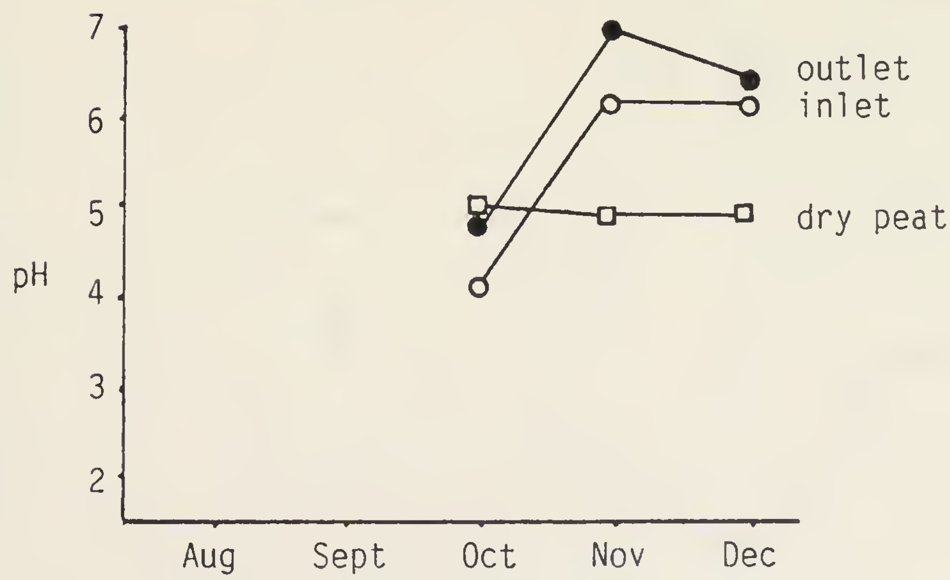


Figures 19 and 20, large wetland organic carbon and small wetland pH in peat.

Large wetland: Organic carbon content in peat

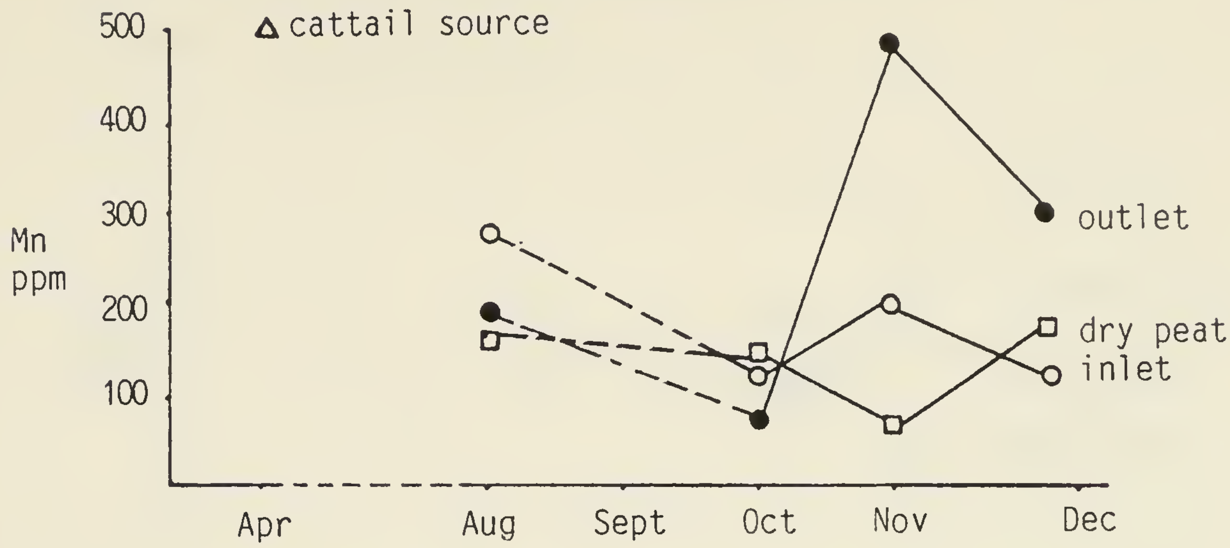


Small wetland: pH changes in peat

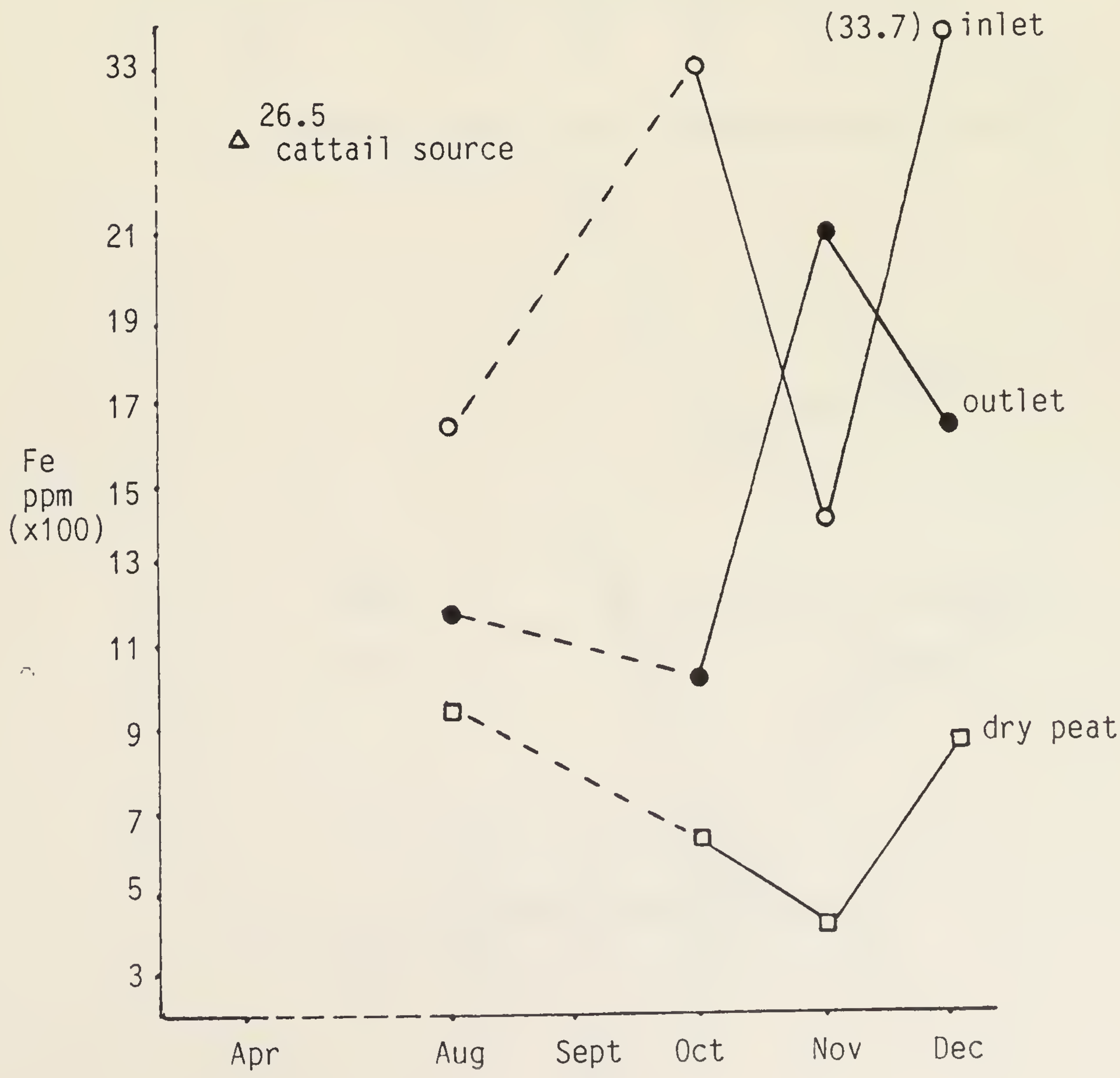


Graphs 21 and 22, small wetland total manganese and iron in peat.

Small wetland: Total manganese concentrations in peat

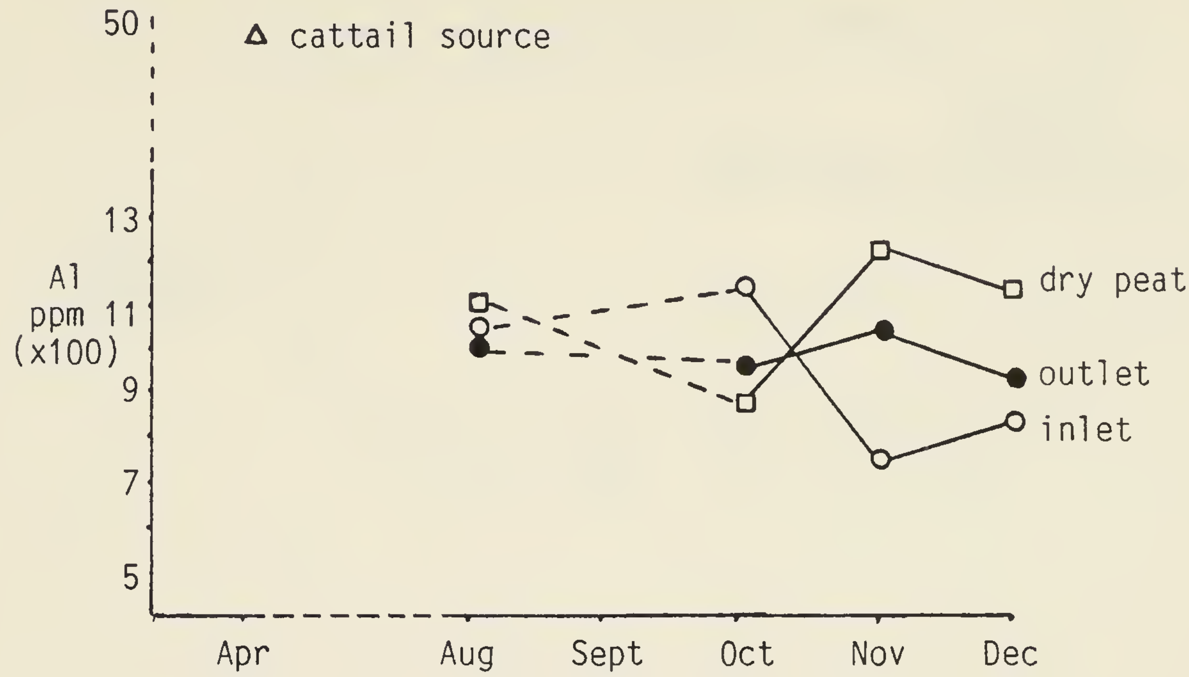


Small wetland: Total iron concentrations in peat

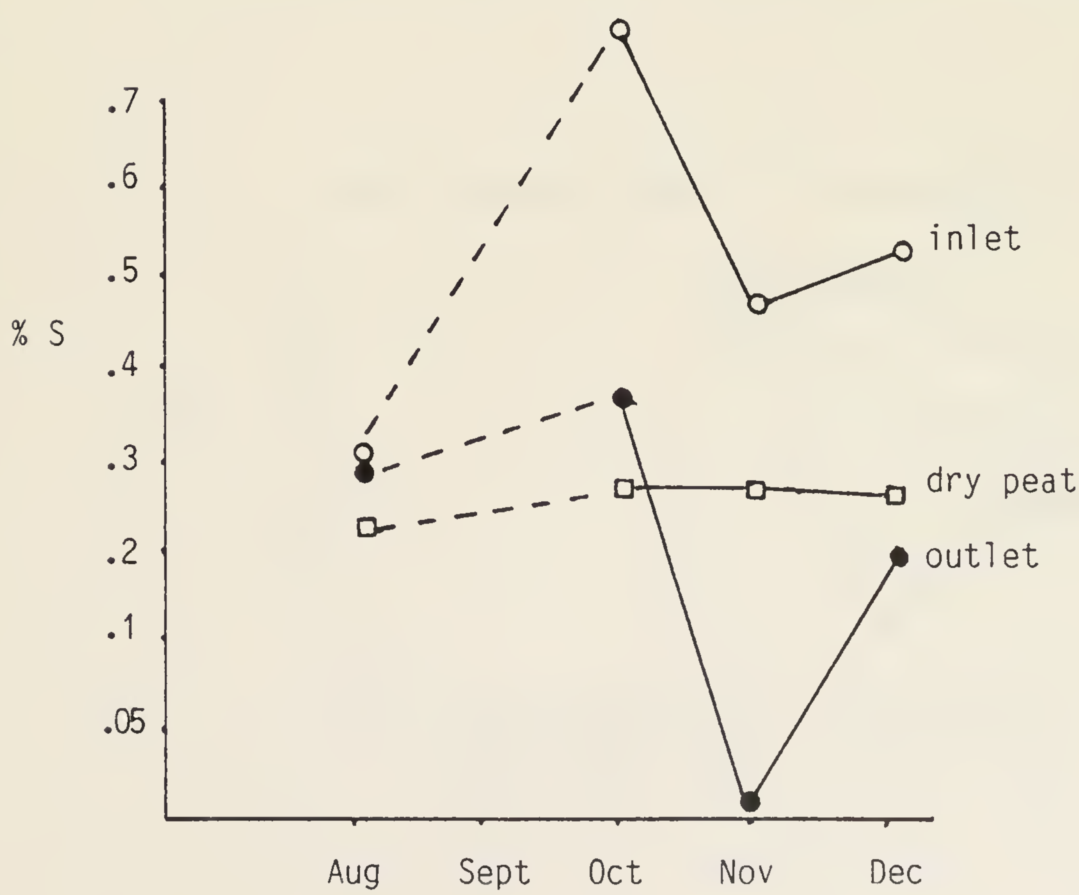


Graphs 23 and 24, small wetland total aluminum and sulfur in peat.

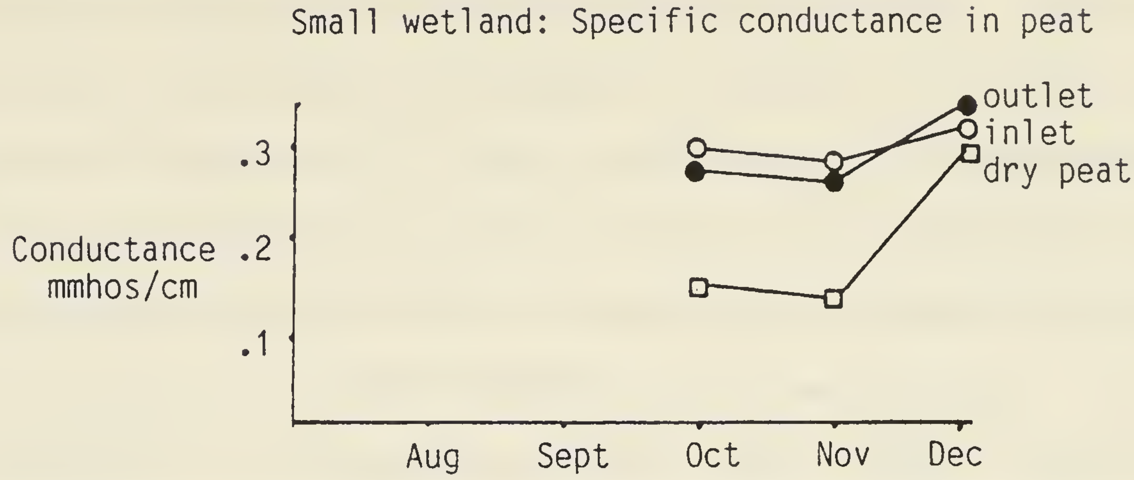
Small wetland: Total aluminum concentrations in peat

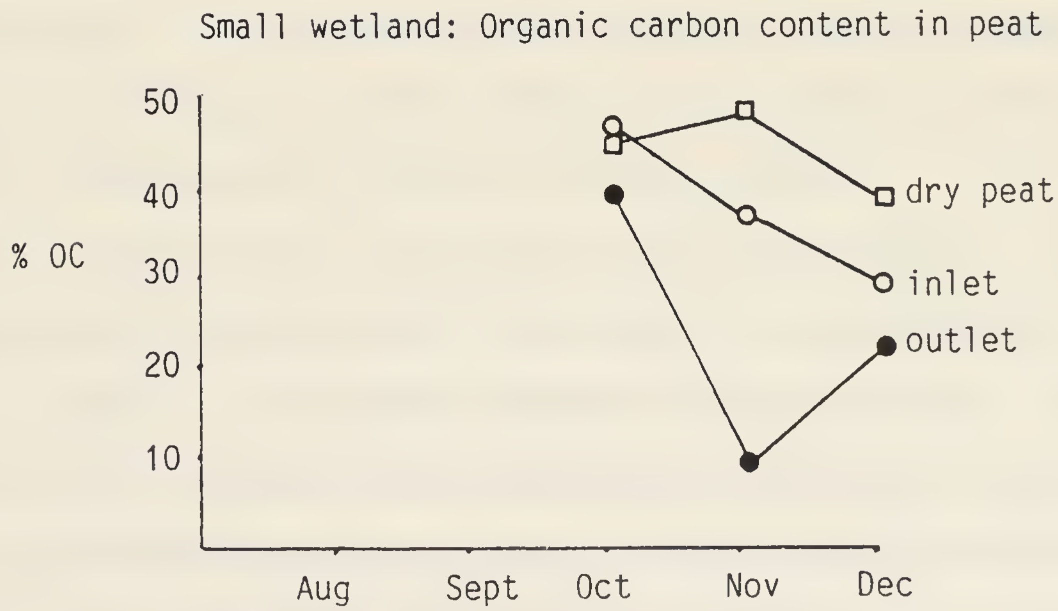


Small wetland: Total sulfur concentrations in peat



Graphs 25 and 26, small wetland specific conductance and organic carbon in peat.





Material from the cattail source is an organic rich silty clay loam or silty clay. Samples analyzed in the early spring, showed total iron concentrations ranging from 24,800 ppm to 28,100 ppm. Total aluminum concentrations ranged from 41,300 ppm. to 57,200 ppm. Total magnesium concentrations ranged from 177 ppm. to 620 ppm. The transplanted cattail mats were approximately 12 inches thick and thus included this material.

The peat was excavated from its source area in south central Montana. It was unprocessed and dried naturally at the wetland site. The peat is loose, shredded, and predominantly fibric. Over the four months that the 'extra' peat (that peat not placed in the wetlands) has sat the measured metals have tended to leach out of the surface. Total iron concentrations declined from 9300 ppm to 4000 ppm over the four month period. Total aluminum concentrations declined from 12,300 ppm to 8900 ppm. Total magnesium concentrations declined from 163 ppm. to 60 ppm.

The monitoring program includes sampling of the peat in the wetland channels at a depth of 0-15 cm. near the inlet and outlet of each wetland. Only four months of data have been collected and analyzed at this writing, so the results presented are necessarily sketchy trends.

In the large wetland, total manganese decreased slightly. The outlet concentration started out less than the inlet's but over the five months has come to equal it. Aluminum showed a similar trend. The iron concentration at the inlet and outlet fluctuated dramatically over time.

In the small wetland aluminum shows a trend similar to that of the large wetland, but manganese increases slightly over time. Iron concentrations fluctuate greatly. As with the large wetland it appears

that over the five months the outlet concentrations have come to exceed those at the inlet.

The pH values for the peat substrate range from about 4 to 7 for the last three months (October, December). These are much higher overall than those for the water samples. The pH of the inlet is less than the outlet over time and in both wetlands, but pH decreases in the large wetland while it increases in the small wetland.

Conductivity appears to have risen slightly for both wetlands, while percent organic carbon varies.

Without more sampling points, interpretation of these results is premature. It is recommended that exchangeable iron, aluminum, and manganese be determined in the future to discover the availability of these cations. Also cation exchange capacties and percent base saturation should be determined. Sampling will be modified to avoid picking up the iron precipitate that has encrusted the peat surface, a factor that may account for the fluctuating iron concentrations found thus far.

Vegetation

The mean concentrations of total aluminum and total iron in Typha roots and rhizomes taken from the treatment ponds are greater than those found in the controls (Table 3). Total manganese and sulfur concentrations do not show as much difference. However, as can be seen by the standard deviations, variablility between samples was high.

Table 3. Mean metals concentrations in Typha samples.

Sample Source	Sample size	Mean Concentration (mg/kg) Al (SD)*	Fe (SD)	Mn (SD)	%S (SD)
CONTROL					
Rhizomes	5	987 (533)	1557 (587)	115 (51)	0.30 (0.14)
Leaves	2	319	416	274	0.14
Roots	1	1555	2360	88	0.67
SOUTH POND					
Rhizomes	5	1732 (874)	3230 (748)	228 (95)	0.44 (0.24)
Leaves	2	532	754	794	0.28
Roots	1	2310	7700	216	1.14
EAST POND					
Rhizomes	5	1188 (799)	2774 (1850)	131 (42)	0.25 (.06)
Leaves	2	744	1655	815	0.27
Roots	1	2500	9700	436	0.38

*(SD)= standard deviation

Metals concentrations measured in Typha rhizome, root and leaf tissues are summarized in Table 3. Total aluminum, total iron and total manganese concentrations from Typha in the experimental wetlands were greater than the metals concentrations measured in Typha from the control area (source of the cattails). Sulfur did not show the same pattern. However, as can be seen from the standard deviations variability

between sampling periods is great. The data are limited, with only two leaf tissue and one root tissue sample having been analyzed.

The metals concentrations in the rhizomes appear to decrease as winter progressed and temperatures dropped. This apparent trend may simply be due to variation between samples.

Only one root tissue sample from each site has been analyzed. The iron concentrations in these root samples were greater than the iron concentrations in the respective rhizomes and the leaves. This was not the case for aluminum, manganese, and sulfur.

Based on the limited data, the manganese concentrations appear to be greatest in the leaves indicating possible translocation of manganese, while iron and aluminum remain in the roots and rhizomes.

Iron and manganese concentrations measured in Johnson Field cattails were much greater than those reported for cattails in eastern United States mine drainage studies (Table 4). Snyder and Aharrah (1984) reported that the greatest concentrations of metals in cattail tissue occurred in June.

Table 4. Mean values for iron and manganese concentrations (ppm) measured in *Typha* in June, Clarion County, Pennsylvania (Snyder and Aharrah, 1984).

Metal	Location	Roots/Rhizomes	Leaves
Iron	mined	378.6	2.6
	non-mined	166.7	1.6

Manganese	mined	90.8	31.0
	non-mined	14.7	22.3

Algae

Algae populations in the constructed wetlands were limited. *Euglena* was by far the most abundant genus, it was also the only non-diatom seen in the four samples examined (two from each the south and east ponds). *Euglena* was very abundant in both the August and November collections from the South Pond, whereas in the East Pond its numbers increased drastically from few cells in August to very abundant in a floristic scan of the November sample.

Euglena has been shown to concentrate trace metals (Hunter, 1986). It has also been found in the Warm Springs Ponds near Anaconda, Montana. These ponds have high concentrations of a variety of heavy metals and are currently being investigated as part of the Butte/Upper Clark Fork Superfund project.

Diatom populations were small in numbers and diversity. A floristic scan of the August collection from the East Pond showed only four species: *Navicula gregaria* (1 frustule), *N. tripunctata* (3 frustules), *Pinnularia borealis* (4 frustules), and *Melosira varians* (2 frustules). No diatoms were observed in the November sample.

Melosira varians has been collected from Silver Bow Creek above the Warm Springs Ponds, but has not been collected from the river downstream of the ponds where water quality is greatly improved. This algae is

apparently tolerant of high metals concentrations.

The South Pond appeared to contain fewer diatoms than the East Pond. The August sample contained only two *Pinnularia borealis* frustules and one *Navicula gregaria* frustule. The November collection revealed only a single *P. borealis* frustule and one *Navicula* sp. frustule.

DISCUSSION

The intent of this project was to develop two experimental wetland ecosystems and evaluate their effectiveness at removing metal ions from AMD and modulating low pH values. Beyond that we hoped to learn how we could make improvements in the design such that future wetland construction projects would meet with greater success.

Kepler (no date) states that a wetland treatment system that can continuously improve AMD quality by even fifty percent is by far a more effective treatment method than a labor dependent chemical system. It is clear that the wetlands did not meet this criteria for success from their creation in July through December 1986. We are constrained in reaching conclusions regarding the effectiveness of the wetlands for several reasons:

1) There has not been adequate time for the wetlands to become established and to collect sufficient data from them to evaluate their performance.

2) The wetlands were not managed consistently throughout this time period. Shortly after construction, in late July, flow through the wetlands

was stopped completely. This is the time when we observed some reduction in iron concentration in the effluent in the large wetland.

In early August more peat was added to the bogs, an amount comparable to that which had been placed in the bogs originally. This accounted in part for the the low residence times observed during the above-described dye tests. The results of the dye tests led to the throttling back of the flow into both wetlands. No change in the quality of the effluent was observed following this throttling back.

3) Construction occurred later than had originally been planned. Consequently the cattails and sedges were planted in July during a period of high air temperatures. The transplanted vegetation undoubtedly endured great stress at this time. The growing season lasted only 6-8 weeks beyond the date of transplanting. Thus it is possible that the plants did not 'work' as well as they might had they been established earlier. The plants appeared to be healthy in the fall with many rhizomes growing. It is anticipated that they will do well in the spring of 1987.

Another consequence of the late construction date was that a diverse algae community did not have time to become established. Very few species of algae were found in the ponds. The blue-green algae which are apparently very effective at removing metals (Kepler, no date) were not observed at all.

Despite these problems several conclusions were reached:

1) The residence time in the ponds was too low. The criterion of 200 square feet of wetland surface area per gallon of flow was met however

this criterion was established for peat bogs and may have been inadequate for our purposes. Kleinmann and Girts (no date) report the preliminary results of experimental wetlands constructed to treat AMD. The authors state that the detention times in the 20 wetlands they reviewed ranged from 0.17 days to 75.4 days with a median time of 4.79 days. These numbers are skewed upward due to the inclusion of three large, deep wetlands in the sample. Despite this it is clear that most researchers currently building wetlands for treatment of AMD are striving for detention times well in excess of those achieved in this study.

2) The peat soils, once saturated, were no longer treating the water entering the wetland. Richardson et al (1978) mentioned low hydraulic conductivity as being characteristic of organic soils. We believe that once the peat soils were saturated with water, the influent no longer came in contact with the peat below the peat-water interface. It had been our intent that the water would flow through the peat and thus be exposed to the high cation exchange and complexing properties of this soil. This did not happen after the first week or two of operation of the wetlands. We believe that this contributes to the discrepancy between the design detention time of thirty-six hours and the observed detention times reported above.

3) The wetlands appear to have removed iron from the AMD during the period of time immediately following construction. It is believed that this occurred because the water was flowing through the unsaturated peat at this time.

4) The cattails are capable of taking up large quantities of iron as

evidenced by the values found in plant tissue, particularly the rhizomes.

RECOMMENDATIONS

During the period July-December 1986 the two experimental wetlands constructed at Johnson Field to treat acid mine drainage did not appear to be effective. This ineffectiveness may be due to one or more of the factors mentioned above. It is essential to collect data for a full growing season to truly assess the role that these wetlands are playing in AMD treatment. During the time of data collection consistency in managment of the wetlands is also essential. The sampling program must be carried out faithfully so that data gaps do not occur. The eighteen months of data that would be available following this continuation of the sampling program should be closely reviewed to determine the effectiveness of the wetlands in removing metals and moderating pH.

The following design changes are recommended for future wetland construction projects:

It will be necessary to increase our design detention time by a factor of two to three and to introduce the influent water in such a way that it will have to move through the peat. Holm and Jones (1985) describe using a rock liner or exfiltration gallery at the upstream end of two artificial bogs to provide uniform inflow of mine water into the entire cross-sectional area of each bog. A similar technique should be used in future wetland construction projects.

The cattails should be planted individually or in small clumps rather than the large mats used in this study. The large mats may have reduced

dessication and thus been responsible for the survival of the cattails through the stressful transplanting phase. However it is felt that cattails in the middle of the mats, the soils of which had high clay content, had little contact with the AMD and thus little opportunity to remove metal ions.

It appears that the peat has an extremely slow hydraulic conductivity, causing the flow through the bog to be short-circuited. We suggest taking vertical core samples to determine movement of metals through the profile, bulk density, and structure characteristics. Any additional peat that is to be introduced to these systems needs to be more carefully examined for favorable baseline characteristics.

An additional condition exists that may be affecting movement of water and metals into the peat. This is the iron precipitate crust that has formed on the surface of the peat. This may in fact be an impermeable layer which prevents the flow of water through the peat.

The limestone used in the channels downstream of the wetlands had a small diameter (3/8 inch). Because iron was not effectively removed in the wetland, the limestone was quickly covered with precipitated iron and rendered ineffective. Had the diameter of the limestone been greater, flow might have percolated through the rock rather than being restricted to flowing on top of the coated crushed limestone.

The size distribution of the limestone in the discharge channel should range from 3/4 inch to 6 inches. This diversity will help insure that water will flow around the limestone even after it is coated with iron and aluminum precipitates.

The design incorporated in this study called for mixing limestone with soil in forming the base of the ponds. In future efforts it is recommended that the limestone be incorporated into the peat. This may help the hydraulic conductivity of the peat.

Our recommendations for the existing wetlands are:

1) Leave them intact as important experimental units

2) Construct linear wetlands following the recommendations outlined above that utilize the discharge from the existing wetlands.

3) Following a strict sampling regime, monitor these wetlands and their extensions for at least five years. It is anticipated that these experimental units will continue to provide valuable insight into how a wetland can provide treatment for AMD. These lessons can be applied to future construction.

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APPENDIX A: CONSTRUCTION COST DATA

Shumaker Construction
BIOLOGICAL TREATMENT RESEARCH
SYSTEM FOR ACID MINE DRAINAGE
---South and East Adits---
Pay Estimate
August 20, 1986

Item	Description	Unit	Qty.	Cost of Work Completed to Date	Cost this Request	Unit Price	Quantities: South Adit	Quantities: East Adit
1.	EARTHWORK	CY	868	$2,604.00	$2,604.00	$3.00	672	196
	TRENCH EXCAVATION & BACKFILL	CY	141	$916.50	$916.50	$6.50	106	35
3.	EXPLORATORY EXCAVATION	HR	3.5	$245.00	$245.00	$70.00	3.5	0
	PROVIDE WATER	100 GAL	680	$1,149.20	$1,149.20	$1.69	460	220
5.	DRAINAGE DITCH	LF	417	$4,170.00	$4,170.00	$10.00	270	147
	DRAINAGE SWALE	LF	130	$1,300.00	$1,300.00	$10.00	0	130
7.	FARM FENCE	LF	1069	$1,389.70	$1,389.70	$1.30	634	435
	FARM FENCE GATE, 16 FT.	EA	2	$160.00	$160.00	$80.00	1	1
	GROUND WATER WELL	EA	0	$0.00	$0.00	$1,636.00	0	0
	FOUR-INCH CLASS 160 PFC PIPE	LF	186	$1,860.00	$1,860.00	$10.00	109	77
	FOUR-INCH GATE VALVE & BOX	EA	4	$3,250.40	$3,250.40	$812.60	2	2
12.	CONNECTION TO EXISTING FOUR-INCH PVC	EA	3	$639.00	$639.00	$213.00	2	1
	FOUR-INCH PVC TEE & RISER	EA	1	$526.00	$526.00	$526.00	1	0
	BENTONITE LINER	SY	786	$1,721.34	$1,721.34	$2.19	445	341
	PROVIDE LIMESTONE	CY	191	$5,730.00	$5,730.00	$30.00	142	49
16.	INSTALL LIMESTONE MIX	CY	152	$684.00	$684.00	$4.50	119	33
	LIMESTONE CHANNEL	LF	157	$527.52	$527.52	$3.36	120	37
18.	PEAT IN-PLACE	CY	360	$10,134.00	$10,134.00	$28.15	240	120
	CATTAIL MATS	SY	168	$16.80	$16.80	$0.10	112	56
20.	WEIR BOX	EA	4	$1,960.00	$1,960.00	$490.00	2	2
	INLET FLOW DIVERTER	EA	1	$490.00	$490.00	$490.00	1	0
	CHANNEL OUTLET BOX	EA	1	$490.00	$490.00	$490.00	1	0
	RE-AERATION STRUCTURE	EA	7	$3,430.00	$3,430.00	$490.00	3	4
	CATWALK, IF NECESSARY	EA	0	$0.00	$0.00	$250.00	0	0
	SUBTOTAL:			$43,393.46	$43,393.46			
	SUBTOTAL OF EXTRAS (See page 2):				$791.63			
					$44,185.09			

LABOR AND MATERIAL EXTRAS REQUIRED FOR COMPLETION OF WORK

HAND LABOR (building berms, South Adit Bog)	2.5 hrs. @ $20.29/hr.	$50.73
966 LOADER	.5 hrs. @ $95/hr.	$47.50
977 LOADER	3.5 hrs. @ $95/hr.	$332.50
28. PVC DRAIN PIPE (Ownership retained by DSL)		$173.40
PVC LINER (Ownership retained by DSL)		$187.50
SUBTOTAL:		$791.63

ANALYSIS OF CONSULTANT COSTS INCURRED
FOR THE MONTANA DEPARTMENT OF STATE LANDS
ABANDONED MINE RECLAMATION BUREAU
AMR PROJECT NUMBER: #86-30.13
JOHNSON BOG
BIOLOGICAL TREATMENT OF MINE WASTEWATER

DATE OF PREPARATION: JANUARY 15, 1987

ITEM DESCRIPTION	AMOUNT
DIRECT LABOR EXPENSE:	
SENIOR ENVIRONMENTAL ENGINEER	$1,888.80
EDITOR/TYPIST	$507.60
SENIOR GEOTECHNICAL ENGINEER	$937.42
SENIOR MINING ENGINEER	$8,195.33
GRAPHICS DESIGNER	$321.71
MINING ENGINEER	$976.84
PRINCIPAL ENGINEER	$85.22
CONSTRUCTION ENGINEER	$357.90
SECRETARY	$340.48
CONSTRUCTION ENGINEER	$406.56
SUBTOTAL:	$14,017.86
ADD REIMBURSABLE EXPENSES:	
EQUIPMENT UTILIZED	$46.00
MILEAGE EXPENSE	$1,444.19
PRINTING EXPENSE	$55.01
SUPPLIES EXPENSE	$101.81
TELEPHONE SERVICE	$205.58
TRAVEL EXPENSE	$243.88
SUBTOTAL:	$2,096.47
SUBCONTRACT LABOR EXPENSE:	
BILL OLSEN	$8,277.05
OEA RESEARCH	$12,057.03
J.E. TAYLOR & ASSOCIATES	$1,720.00
SHUMAKER TRUCKING & EXCAVATING	$49,785.09
SUBTOTAL FOR SUBCONTRACT LABOR:	$71,839.17
SUBTOTAL FOR REIMBURSEABLE EXPENSES:	$73,935.64
TOTAL PROJECT COSTS:	$87,953.50